



Experimental Study on Mechanical Properties of Grouted Sleeves with Different Materials

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Abstract: To clarify the differences in mechanical properties between the new seamless steel pipe rolled grouting sleeve and ductile iron fully grouted/semi-grouted sleeves, three groups of specimens (9 in total) were designed for uniaxial tensile tests. The failure modes, ultimate loads, ultimate displacements, and strain distribution laws of the specimens were analyzed. The results show that all three types of sleeves undergo complete elastic, yield, strengthening, and necking stages, with the failure mode being steel bar fracture in all cases. Among them, the new grouting sleeve exhibits the best ductility, followed by the ductile iron fully grouted sleeve, while the ductile iron semi-grouted sleeve shows the worst ductility. The most critical section of the new grouting sleeve is located at the first annular rib in the middle; for the ductile iron fully grouted sleeve, it is in the middle of the sleeve; and for the ductile iron semi-grouted sleeve, it is at the threaded end and the size-varying region. Based on the test results, structural optimization suggestions for the three types of sleeves are proposed, which provide a reference for the engineering application of grouting sleeves in prefabricated buildings.

Keywords: prefabricated buildings, grouting sleeves, uniaxial tensile tests, mechanical properties, failure modes

1. Introduction

Grouted sleeves are core components for steel bar connection in prefabricated concrete structures, and their mechanical properties directly affect the overall safety of the structure. In the 1960s, the grouted sleeve connection method was proposed [1], and since then, numerous scholars at home and abroad have carried out research on the development and working mechanisms of different types of sleeves. Eliya Henina [2] developed a non-proprietary grouted sleeve that is cost-effective, easy to manufacture, and capable of compensating for production errors.

Currently, ductile iron fully grouted sleeves and semi-grouted sleeves are commonly used in engineering projects. In contrast, the new seamless steel pipe rolled grouted sleeve has gradually attracted attention due to its novel structure and outstanding economic benefits. However, research on the comparison of mechanical properties among these three types of sleeves remains insufficient.

In this study, uniaxial tensile tests were conducted to systematically investigate the failure characteristics, load-displacement responses, and strain distribution laws of the three types of sleeves. The advantages and disadvantages of their mechanical properties, as well as the key controlling factors, were clarified, providing experimental basis for the selection and optimized design of sleeves.

2. Experimental Overview

2.1 Experimental Design

In the experiment, three types of sleeves were selected: new grouted sleeves fabricated from Q390B low-alloy seamless steel pipes [3], ductile iron fully grouted sleeves of type GTZB4-20C, and ductile iron semi-grouted sleeves of type GTZQ420A. There were 3 specimens in each group, totaling 9 specimens. HRB400-grade steel bars with a diameter of 20 mm were adopted, and the anchorage length was uniformly set to 160 mm (8 times the steel bar diameter).

2.2 Loading Protocol and Strain Gauge Arrangement

In accordance with the Technical Specification for Mechanical Splices of Steel Bars (JGJ107-2016), a high-speed impact testing machine was used to conduct unidirectional tensile tests at a loading rate of 5 kN/s until the specimens failed. Arrangement of strain measurement points: Both the new grouted sleeves and ductile iron fully grouted sleeves were bonded with axial (Series Z) and circumferential (Series H) strain gauges, covering the ends, middle parts, and key stress-bearing areas of the sleeves.

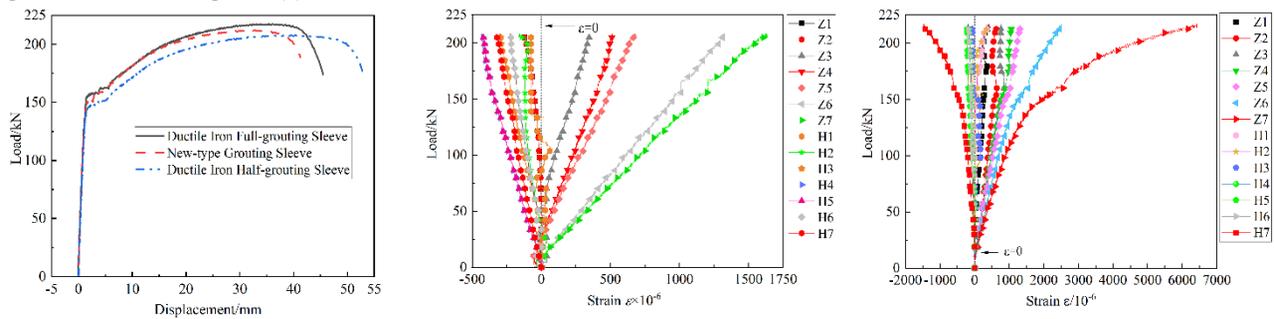
3. Test Results and Analysis

3.1 Failure Modes

The final failure mode of all three types of sleeve specimens was steel bar fracture, with no sleeve cracking or grouting material detachment observed. During the loading process, signs of slight slippage appeared at the threaded end of the semi-grouted sleeves, while no significant slippage was detected throughout the loading process for the other two types of sleeves. This indicates that the annular ribs of the new grouted sleeves and the protruding ribs of the ductile iron fully grouted sleeves exhibit superior confinement effects on the grouting material.

3.2 Analysis of Load-Displacement Curves

The load-displacement curves of the three types of sleeves all exhibit complete elastic, yield, hardening, and necking stages, as shown in Figure 1(a).



(a) Load-Displacement Curves of Three Types of Grouted Sleeves (Average Values) (b) Strain-Load Curves of New Grouted Sleeves (c) Strain-Load Curves of GTZQ420A Sleeves

Figure 1. Experimental curve

Elastic stage: The displacement differences among the three types of sleeves are small. This is attributed to the minimal deformation of steel bars and the excellent bond performance between the grouting material, sleeves, and steel bars, which ensures effective force transfer without obvious relative slip.

Hardening and necking stages: The displacement differences become significant. Among the specimens, the ductile iron semi-grouted sleeves exhibit the largest ultimate displacement, followed by the ductile iron fully grouted sleeves, while the new grouted sleeves show the smallest ultimate displacement.

Ultimate load: The ductile iron fully grouted sleeves achieve the highest ultimate load, followed by the new grouted sleeves, and the ductile iron semi-grouted sleeves have the lowest ultimate load.

Ductility: The new grouted sleeves have the highest ductility coefficient (with an average value of 1.91), followed by the ductile iron fully grouted sleeves (average: 1.41), and the ductile iron semi-grouted sleeves have the worst ductility (average: 1.27). This phenomenon is mainly because the threaded connection of semi-grouted sleeves weakens the strength of steel bars and easily induces slippage between the steel bar and sleeve, which reduces the overall deformation capacity of the connection.

3.3 Analysis of Strain Distribution

As shown in Figures 1(b) and 1(c): For the new grouted sleeves: The maximum axial strain is 0.0016, and the maximum circumferential strain is 0.0004. All circumferential strains are negative (indicating compression), while all axial strains are positive (indicating tension) except for those at the end measuring points. The entire cross-section remains in the elastic stage, with uniform strain distribution.

For the ductile iron fully grouted sleeves: The maximum axial strain is 0.0064, and the maximum circumferential strain is 0.0015. All circumferential strains are positive (indicating tension) except for those at the end measuring points, and the entire cross-section is under axial tension. The strain values are much larger than those of the new grouted sleeves, and localized areas have entered the plastic stage.

Most critical cross-sections: For the new grouted sleeves, it is located at the first annular rib in the middle section; for the ductile iron fully grouted sleeves, it is at the middle of the sleeve; and for the semi-grouted sleeves, it is at the threaded end and the dimension-varying region.

4. Conclusions

All three types of grouted sleeves undergo elastic, yield, hardening, necking, and steel bar fracture stages during uniax-

ial tensile failure, and they exhibit stable and reliable failure modes.

The new grouted sleeves feature uniform strain distribution, the best ductility, and require lower strength of grouting material; the ductile iron fully grouted sleeves have the highest ultimate load and sufficient safety margin; while the ductile iron semi-grouted sleeves show the worst ductility, are prone to slippage at the threaded end, and have the smallest safety margin.

The three types of sleeves differ in the positions of their most critical cross-sections, which are mainly associated with their structural configurations and confinement mechanisms.

5. Suggestions for Improvement

New grouted sleeves: Reduce the depth of the first annular rib in the middle section, optimize the layout position of annular ribs, or add a necked section at the sleeve end to enhance the confinement effect on the grouting material.

Ductile iron fully grouted sleeves: Given their sufficient safety margin, the wall thickness can be appropriately reduced to decrease self-weight and cost, thereby facilitating construction and installation.

Ductile iron semi-grouted sleeves: Increase the length of the threaded end, thicken the wall thickness of the dimension-varying region, and reduce the necking angle to alleviate stress concentration.

Acknowledgments

This work was supported by the 2025 University-Level Scientific Research Project of Guangdong Technology College (Project No.: 2025YBZK012) and the Higher Education Teaching Reform Project of Guangdong Technology College (Project No.: JXGG2025030).

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