Experimental Research of Polyurethane Filled Double Skin Steel Tube

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Abstract. Based on the experiments, the mechanical properties of polyurethane filled double skin tubular (PFDSST) members with different hoop coefficients and slenderness ratios under axial compression have been studied intensely.

Keywords: PFDSST; polyurethane; hoop coefficient; properties.

1. Introduction
This paper proposes a new form of composite pipe in which polyurethane elastomer is infused between the inner and outer steel tubes to form a new composite component--Round hollow sandwich steel tube polyurethane composite member. It has superior performance than single steel structure, and has the characteristics of simple structural form, good ductility, strong anti-fatigue and anti-corrosion ability, superior impact resistance and low production.

2. Specimens design and test equipment
2.1. Specimen size
The length-to-diameter ratio of the standard specimens of the PFDSST specimens in this test was 2.86 to 6.86 (theoretical value). The author divides all the test pieces into five categories according to the hoop rate: SP0, SPa, SPb, SPc and SPd. Each category is divided into five test pieces according to the length-to-diameter ratio. The basic dimensions of the PFDSST specimen are shown in Table 1.

| Type | Test Piece Number | Test Piece Length L (mm) | Measured Length L0 (mm) | Inner Tube Specification D1×T1 (mm×mm) | Outer Tube Specification D2×T2 (mm×mm) | Measured Aspect Ratio λ |
|------|-------------------|--------------------------|-------------------------|---------------------------------------|---------------------------------------|------------------------|
| SP0  | 1                 | 200                      | 200.22                  | 0×0                                   | 70.78×3.54                           | 2.83                   |
|      | 2                 | 300                      | 300.36                  | 0×0                                   | 70.74×3.48                           | 4.25                   |
|      | 3                 | 400                      | 399.78                  | 0×0                                   | 71.08×3.62                           | 5.62                   |
|      | 4                 | 480                      | 480.32                  | 0×0                                   | 70.84×3.52                           | 6.78                   |
|      | 1                 | 200                      | 200.06                  | 25.18×2.62                           | 70.98×3.62                           | 2.82                   |
|      | 2                 | 300                      | 300.18                  | 25.12×2.58                           | 70.82×3.46                           | 4.24                   |
| SPa  | 3                 | 400                      | 400.58                  | 25.02×2.52                           | 70.82×3.48                           | 5.66                   |
|      | 4                 | 480                      | 479.96                  | 25.22×2.46                           | 70.92×3.52                           | 6.77                   |
|      | 1                 | 200                      | 199.96                  | 30.12×2.42                           | 70.68×3.48                           | 2.83                   |
|      | 2                 | 300                      | 299.78                  | 30.24×2.44                           | 70.78×3.56                           | 4.24                   |
| SPb  | 3                 | 400                      | 400.34                  | 30.02×2.38                           | 70.76×3.48                           | 5.66                   |
|      | 4                 | 480                      | 480.56                  | 30.10×2.48                           | 70.82×3.56                           | 6.79                   |
In Table 1:

λ: Theoretical aspect ratio of PFDSST specimens, \( \lambda = L / D \);

ζ: Hoop rate of PFDSST test piece, \( \xi = A_{fs} / A_{fp} \).

3. Experimental research

3.1. Test phenomenon and analysis

Figure 1. Strain recovery of polyurethane of PFDSST members

After the PFDSST specimen is destroyed, the polyurethane layer is not destroyed, polyurethane and steel pipe do not peel off each other. When the test is completed and completely unloaded, the polyurethane in the PFDSST specimen will undergo partial deformation recovery, and since the polyurethane has very good ductility, the phenomenon in Fig. 1 will occur.

3.2. Analysis of test results

3.2.1. Ultimate bearing capacity of the test piece. It can be seen from Fig. 2 and Table 2 that as the aspect ratio increases, the ultimate load carrying capacity of the PFDSST specimen becomes smaller. The ultimate bearing capacity of PFDSST specimens with small aspect ratio is greatly improved compared with the nominal stress; the ultimate bearing capacity of PFDSST specimens with larger long diameter is also higher than the nominal stress.

Figure 2. Equivalent load factor—strain curves of PFDSST members
Table 2. Ultimate bearing capacity and nominal stress of each category

| Types | Test Piece Number | $N_u$ (kN) | $N_v$ (kN) | $N_u$ $N_v$ |
|-------|-------------------|------------|------------|------------|
| SP0   | 1                 | 234.87     | 359.51     | 1.53       |
|       | 2                 | 239.26     | 350.02     | 1.52       |
|       | 3                 | 240.07     | 335.85     | 1.41       |
|       | 4                 | 236.99     | 306.91     | 1.32       |
|       | 1                 | 295.14     | 487.34     | 1.65       |
|       | 2                 | 297.84     | 444.93     | 1.55       |
| SPa   | 3                 | 304.62     | 401.06     | 1.40       |
|       | 4                 | 309.53     | 392.23     | 1.37       |
|       | 1                 | 300.84     | 464.02     | 1.68       |
|       | 2                 | 304.03     | 442.13     | 1.57       |
| SPb   | 3                 | 301.26     | 399.31     | 1.45       |
|       | 4                 | 305.93     | 389.11     | 1.38       |

3.2.2. Calculation formula. The ultimate compressive bearing capacity formula can be expressed as:

$$ N_u = k f_p A_p + f_s A_s $$

Formula:

$k$: Improvement coefficient of polyurethane strength inside steel-polyurethane composite pipe

$f_p$: Polyurethane compression yield strength (MPa)

$f_s$: Steel pipe yield strength (MPa)

$A_p$: Polyurethane area ($mm^2$)

$A_s$: Steel pipe area ($mm^2$)

$k = 0.7713 \xi + 0.8483$

Formula: Hoop coefficient $\phi_p = \frac{A_p f_p}{A_p f_p}$

Formula 1 only applies to the case where the test piece is short, but not for the long test piece. Introducing the reduction factor according to the literature [7] $\phi_p$:

$$ \phi_p = 1 - 0.115 \sqrt{L_0 / D - 4} \quad L_0 / D \leq 20 $$

Formula:

$N_u$: Measured ultimate load $N_u = k f_p A_p + f_s A_s$ $N_o$: According to the previous section formula $N_o = A_p f_p (1.7713 \xi + 0.8483)$

Steel-polyurethane composite pipe bearing capacity considering the reduction factor of the influence of length to fine ratio, by fitting the curve:

$$ \phi_p = 1 - 0.1148 \sqrt{L_0 / D - 2.6667} $$

$L_0$: Calculate the length, here take the actual length of 0.7 $D$: The outer diameter of the steel pipe.

Therefore, the formula for calculating the ultimate bearing capacity of PFDSSST specimens is summarized in this paper, see Equation 3.47 and Equation 3.48.

1. Calculation formula for ultimate bearing capacity of short PFDSSST specimens:

$$ N_u = k f_p A_p + f_s A_s $$

2. Calculation formula for ultimate bearing capacity of long PFDSSST specimens:
3.3. Influence law of influencing factors

3.3.1. Influence of hoop rate on mechanical properties of components. It is found from Fig. 6 that the stability of $SP_0$, $SP_a$, $SP_b$, $SP_c$, $SP_d$ five types of components becomes stronger as the hoop rate increases. The main reason is that the larger the hoop rate, the greater the axial compressive stiffness of the PFDSST specimen, and the greater the binding force of the steel tube to the polyurethane. As the external load becomes larger, the three-way pressure state of the polyurethane layer becomes more obvious.

\[ N_\alpha = \phi_\alpha A_f (1.7713 \zeta + 0.8483) \]

(6)

3.3.2. Effect of length to diameter ratio on mechanical properties of components. As the aspect ratio becomes larger, the ultimate bearing capacity of the component decreases greatly, and the ductility also deteriorates a lot.

3.4. Working process of PFDSST test piece

3.4.1. Working process of PFDSST short test piece. As the axial load increases on the PFDSST specimen, the combined performance of the PFDSST component can be roughly divided into four phases:

(1) The oa segment is a flexible working phase that is very close to a straight line. (2) The ab segment is an inelastic working phase. (3) The bc segment is the strengthening phase (4) Ductile transition

4. Conclusion

The calculation formula of ultimate bearing capacity of PFDSST specimens is derived by linear regression and fitting curve. The variation of mechanical properties of PFDSST specimens is summarized in the case of changes in hoop ratio $\zeta$ and aspect ratio $\lambda$.

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