Mechanical properties and constitutive relationship of Chinese 7A21 aluminum alloy

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Abstract. For the design and calculation of transmission line repair tower using high strength aluminum alloy materials, it is necessary to fully understand the mechanical properties and constitutive model of aluminum alloy materials. In this paper, the mechanical properties and constitutive relations of the newly developed 7A21 high strength aluminum alloy for processing L50×5 and L80×6 profiles are experimentally studied, the newly developed grades of Aluminum alloy include tensile strength $f_u$, nominal yield strength $f_{0.2}$, elongation at break $\delta_{10}$ and section shrinkage $\psi$, and fit the constitutive model, the basic data support is improved for the design and application of the aluminum alloy material in engineering structure.

1. Introduction
Before the newly developed materials are applied in engineering, the Mechanical Properties and other basic material properties must be obtained accurately. The purpose of this project is to obtain the tensile strength $f_u$, nominal yield strength $f_{0.2}$, elongation $\delta_{10}$ and section shrinkage $\psi$, as well as the constitutive relationship model for the 7A21 aluminum alloy.

2. Specimen design
7A21 aluminum alloy made in China is used for making tensile test pieces. Samples were taken from angle aluminum profiles of different specifications, 3 samples were taken from each specification, and tensile tests were carried out on the samples respectively. All Specimens are machined in accordance with the Test pieces and methods for tensile test for wrought aluminium and magnesium alloys products [1]. The processing drawing of the test piece is shown in figure 1. The aluminum alloy plate number and the section size of the test piece are shown in table 1.

![Figure 1 Drawing of standard tensile specimen](image-url)
Table 1 Profile specification for material properties test pieces

| Angle aluminium specification | Thickness | Width | Original Gauge | Parallel length | Radius of arc | Dimension of clamping end | Total length |
|------------------------------|-----------|-------|----------------|-----------------|--------------|---------------------------|-------------|
| L50×5                        | 5         | 12.5  | 50             | 80              | 15           | 80                        | 42.5 270    |
| L80×6                        | 6         | 12.5  | 50             | 80              | 15           | 80                        | 42.5 270    |

The summary information of all test pieces is shown in table 2.

Table 2: Summary of all tensile specimens

| Specimen number | Test temperature | Sampling specification | Quantity | explanation |
|-----------------|------------------|------------------------|----------|-------------|
| 1-1, 2, 3       | 20°C             | L50×5                  | 3        | Room temperature 12 test pieces |
| 2-1, 2, 3       | L80×6            | 3                      |          |             |

Due to the possible dimension error of tensile specimens, the actual dimensions of all tensile specimens were measured before the formal test. The measured results of the cross-section are shown in table 3. The widths and thicknesses of the three sections were measured for each tensile specimen.

Table 3 Field table of cross section for all tensile specimens

| Specimen number | section 1 | section 2 | section 3 |
|-----------------|-----------|-----------|-----------|
| Width mm        | Thickness mm | Width mm | Thickness mm | Width mm | Thickness mm |
| 1-1             | 12.52     | 5.07      | 12.51     | 5.08      | 12.50     | 5.06      |
| 1-2             | 12.61     | 4.99      | 12.63     | 5.01      | 12.71     | 5.00      |
| 1-3             | 12.50     | 5.02      | 12.51     | 5.01      | 12.51     | 5.05      |
| 2-1             | 12.46     | 6.10      | 12.50     | 6.10      | 12.49     | 6.13      |
| 2-2             | 12.54     | 6.08      | 12.51     | 6.06      | 12.56     | 6.06      |
| 2-3             | 12.53     | 6.05      | 12.49     | 6.14      | 12.54     | 6.11      |

3 Test results

3.1 Tensile test results at room temperature from samples of angular aluminium

A total of 6 specimens were drawn at room temperature from angular aluminium. The mechanical properties of each specimen are detailed in table 4. The specific mechanical properties given in table 4 include elastic modulus $E$, tensile strength $f_u$, nominal yield strength $f_{0.2}$, elongation $\delta_{10}$ and section shrinkage $\psi$.

Photographs of all room temperature specimens taken from angular aluminium are shown in figure 2. It can be seen from table 4 that the elastic modulus of each specimen is about 70000MPa, the tensile strength of each 7A21 specimen is about 450MPa, and the elongation of each specimen is higher than 10%.

Table 4 Mechanical properties of tensile specimens sampled from angle aluminium at room temperature

| Specimen number | $E$ / MPa | $f_{0.2}$ / MPa | $f_u$ / MPa | $\delta_{10}$ | $\psi$ | Notes |
|-----------------|-----------|-----------------|-------------|---------------|-------|-------|
| 1-1             | 68398     | 429.00          | 458.87      | 15.88%        | 34.54%|       |
| 1-2             | 69087     | 427.00          | 460.39      | 16.28%        | 30.46%|       |
| 1-3             | 69106     | 427.00          | 454.17      | 16.48%        | 32.96%|       |
| 2-1             | 66288     | 412.00          | 443.05      | 15.02%        | 37.52%|       |
4. Analysis of test results

Aluminum alloy’s stress-strain curve is not like steel, it does not have obvious yield platform, but a continuous smooth curve[2]. Much research has been done on the constitutive relations of aluminum alloys, the most common of which is the Ramburg-Osgood model[3]. In 1939, Ramberg and Osgood proposed a three-parameter model to describe the constitutive relations of aluminum alloys. The Ramberg-Osgood model is now widely used because its expected properties are very close to the actual properties of aluminum alloys[4,5]. This model was also used by the ECCS light alloy structure committee in developing the European Aluminium Alloy Structure Recommendation (1978)[6]. The model is expressed as follows:

\[ \varepsilon = \frac{\sigma}{E} + \left( \frac{\sigma}{B} \right)^n \]  

(1)

\( E \) is the elastic modulus at the origin, and \( n \) and \( b \) are the parameters determined by the experiment.

Assume that \( f_{0.2} \) is the stress corresponding to the residual strain equal to 0.002, from formula (1):

\[ 0.002 = \varepsilon - \frac{f_{0.2}}{E} = \left( \frac{f_{0.2}}{B} \right)^n \]  

(2)

Replace formula (2) with formula (1):

\[ \varepsilon = \frac{\sigma}{E} + 0.002 \left( \frac{\sigma}{f_{0.2}} \right)^n \]  

(3)

It is known from formula (3) that \( n \) is a parameter describing strain hardening. When \( n = 1 \), the stress-strain relationship of the material is linear elastic, and when \( n = \infty \), the stress-strain relationship of the material is ideal elastoplastic. Suppose \( f_{0.1} \) is the stress corresponding to a residual strain equal to 0.001, from formula (1):

![Figure 2 Photograph of tensile specimens taken from angle aluminium at room temperature after failure](image-url)
Derived from formula (2) and formula (4):
\[
0.001 = \varepsilon - \frac{f_{0.1}}{E} = \left(\frac{f_{0.1}}{B}\right)^n
\]

(4)

If the parameters \(f_{0.1}, f_{0.2}\) and elastic modulus \(E\) are known, the exponent \(n\) can be calculated from formula (5) and the stress-strain curve of the material can be described from formula (2).

Based on the measured stress-strain curves, the R-O fitting curves of the non-welded specimens at room temperature are obtained as shown in figure 3. As can be seen from figures, the constitutive relation of aluminum alloy basically satisfies the Ramburg-Osgood model.

5. Conclusion
In this paper, the mechanical properties of Chinese 7A21 aluminum alloy at room temperature were studied by tensile test. The Specific Mechanical Properties include tensile strength \(f_u\), nominal yield strength \(f_{0.2}\), elongation \(\delta_{10}\) after breaking and section shrinkage \(\psi\). The results show that the stress-strain curve of aluminum alloy does not have an obvious yield platform like that of steel, but is a continuous and smooth curve, and the constitutive relation of aluminum alloy at room temperature basically satisfies the Ramburg-Osgood model.

Acknowledgments
This study was financially supported by "Research and application of Emergency Restoration System for overhead transmission lines" (Grant No. GZHJXM20180109), Science and technology project of China Southern Power Grid.
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