

Research status and development trend of mechanical properties of 7 series ultra-high strength aluminum alloy

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Abstract. Aluminum alloy material has the characteristics of good durability, corrosion resistance, light weight, easy processing, maintenance-free, recyclable, etc. It has a wide range of application prospects in the field of civil engineering, but with the increase of structural load complexity, the strength of aluminum alloy material has been put forward new requirements. In this paper, the engineering application of 7 series ultra-high strength aluminum alloy materials is introduced, and the mechanical properties of several commonly used 7 series ultra-high strength aluminum alloy materials are compared. Based on the shortcomings of the existing research, the development direction of the research on the properties of 7 series ultra-high strength aluminum alloy materials and components is prospected, in order to promote the engineering application of high-strength aluminum alloy materials, and provide reference for the formulation of related standards for aluminum alloys.

1 Introduction

Aluminum alloy material has the advantages of light weight and high strength, good corrosion resistance, good processing performance, beautiful appearance, low maintenance cost in the later period, and is widely used in aerospace, ships, rail transit, automobiles, electronic appliances, food packaging, building structure, decoration, national defense and other fields, especially in the field of long-span space structure applications are increasing[1]. However, with the development of curved surface shape, span and use scenario, the commonly used 6 series aluminum alloy has been difficult to meet the needs of material strength for long-span space structure, long-span bridge, special structure and other projects. 7 series aluminum alloy with aluminum as the basic element, the main alloying elements added are Zn, Mg, Cu, Fe, Si, Mn, Ti, Cr, etc., is a kind of heat-treatable strengthened aluminum alloy, with high specific strength and hardness, good processing performance, good corrosion resistance and high toughness, "General industrial aluminum and aluminum alloy extruded profiles" (GB/T6892-2015)[2], the chemical element composition of a variety of 7 series aluminum alloy materials, basic material mechanical properties are specified. The yield strength of high-strength aluminum alloy is high, and the

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use of 7-series high-strength aluminum alloy can reduce the section size of the component, and avoid the technical and economic problems such as the extrusion difficulty of the large-section aluminum alloy component and the large amount of aluminum. And high strength aluminum alloy corrosion resistance is good, for the corrosive environment requirements of high harbor structures, offshore wind power foundation and other important structural components, are very ideal materials. Therefore, the application prospect of high-strength aluminum alloy in the field of civil engineering is very broad.

Domestic and foreign scholars on the 7××× series aluminum alloy research mainly focuses on the material characteristics, processing technology and other levels, the bearing performance of the corresponding components, node connection, structural system and other research is relatively lacking, is not enough to support its full application in the field of large-span spatial structure. This paper introduces the research status of high performance aluminum alloy from the aspects of material mechanical properties, component bearing properties and welding connection properties of 7××× series high strength aluminum alloy, summarizes the existing achievements, and puts forward the problems that need further research, so as to provide reference for future engineering application and in-depth research of high strength aluminum alloy.

2 7 series high strength aluminum alloy material introduction

Ultra-high strength aluminum alloy mainly refers to 7XXX series containing elements Al-Zn-Mg-Cu alloy, its tensile strength are above 500 MPa, with high specific strength and specific stiffness, the series of aluminum alloy not only high hardness, strength, and plastic toughness is also good, with easy processing and other advantages, Therefore, it is widely used in aviation, military, civil industry and other fields [3][6]. From the 1940s to the 1970s, 7075-T6, 7078-T651, 7075-T651, 7150-T651 and other alloys were successively developed. In the 1990s, some industrial developed countries developed a new generation of ultra-high strength aluminum alloy, which adopts advanced jet forming technology to control the content of Zn element above 8%, and then widely used in the field of transportation, becoming a high-stress structural part with high strength and good corrosion resistance [7]. At present, Al-Zn-Mg-Cu aluminum alloy has dozens of standard grades of different components in the world, and the corresponding alloy heat treatment standard processes are as high as hundreds of kinds.

3 Research status of mechanical properties of materials

The current national standard "Aluminum alloy Structure design Code" (GB50429-2007)[8] has no provisions on the design strength value of 7 series high-strength aluminum alloy materials. In the aluminum alloy structure standards, only the Shanghai local standard "Technical Standard for Aluminum Alloy lattice Structure" (DG/TJ 08-95-2020)[9] stipulates the strength design value of 7075-T6 and 7020-T6. Still in the re-revised draft of the "Aluminum alloy structure technical Standard" (GB 50429, revised draft) in accordance with different sheet thickness is given a more detailed 7020-T6 strength design value, but the strength design value in the two specifications is not unified, the future need to do further research, specifically specify the design index of high-strength aluminum alloy materials, in order to facilitate the use of engineering.

Domestic research on the mechanical properties of 7××× high strength aluminum alloy is mainly focused on the brand 7075-T6, 7A04-T6, 7075-T73 and other three kinds, there are also a small number of research on the brand 7A05-T6, 7020-T6. Domestic research work on the mechanical properties of aluminum alloy materials started late, in 2004, Li

Jingyong et[10] al., according to the needs of Zhou-bridge structure, discussed the mechanical properties of 7005-T6, 7A05-T6 aluminum alloy (ultimate strength of about 480MPa). In 2019, Li Jinjun et[11][12] al. completed 15 static tensile tests of material properties of round pipe and tube, and compared the stress-strain curves obtained from the tests with the common constitutive models of aluminum alloys such as Ramberg-Osgood (R-O) model, Baehre model and Mazzolani model. Among them, Ramberg-Osgood (R-O) model is the best, which is more suitable for describing the constitutive relationship of 7A04-T6 aluminum alloy. The nominal thickness of specimens covered in this study is 3mm, 4mm, 5mm, 6mm, 10mm and 24mm, covering the needs of practical engineering.

When Wang Yuanqing et[13][14][15] al. studied the overall stability of L-shaped and box-shaped axial compression members of high-strength aluminum alloys, they carried out a monotone tensile property test of 7A04-T6 aluminum alloys. The maximum nominal yield strength and tensile strength were 499.8MPa and 601.5MPa respectively, and the failure mode was shown in FIG. 1. In 2021, Wang Yuanqing's team [16] carried out monotone tensile properties tests on a number of specimens of 7A04-T6 and 7075-T6 high-strength aluminum alloy members with I-shaped, box-shaped and circular sections when studying their bending, axial compression and bending properties. It is recommended that the design value of tensile, compressive and bending strength f of 7A04-T6 high-strength aluminum alloy at room temperature should be 410MPa, the design value of shear strength f_v should be 235MPa, and the design value of ultimate tensile, compressive and bending strength $f_{u,d}$ should be 465MPa for the calculation of components.

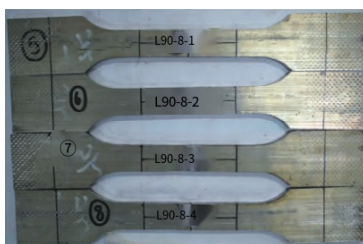


Fig. 1. The result of 7A04-T6 material property test.

Hu Xiaoguang et[17][18] al. also studied the tensile properties of domestic 701 and 703 new high-strength aluminum alloy materials. The results showed that: The nominal yield strength $f_{0.2}$ of domestic 701 aluminum alloy is about 423.7MPa and the ultimate strength f_u is about 452.2MPa. The nominal yield strength $f_{0.2}$ of domestic 703 high-strength aluminum alloy is about 490.8MPa and the ultimate strength f_u is about 520.6MPa, which is generally lower than the corresponding strength of 7A04-T6 aluminum alloy.

The constitutive relation of aluminum alloy under cyclic load is an important basis for accurate calculation of seismic response of aluminum alloy structure. The hysteretic properties of high-strength aluminum alloy are still limited. Wang Yuanqing et[19][20] al. carried out monotone tensile and various cyclic loading tests on 17 7A04 high-strength aluminum alloy material specimens and numerical analysis of hysteretic properties. The research shows that: The 7A04 high-strength aluminum alloy specimens showed a typical cyclic hardening phenomenon under cyclic loading. When the compressive strain reached 1%, the stiffness and strength deteriorated, showing the characteristics of mixed strengthening, that is, the isotropic strengthening + follow-up strengthening mode; The hysteretic curve of the specimen is full, and the 7A04 high-strength aluminum alloy shows good hysteretic properties. The calibration Chaboche model can accurately predict the hysteretic properties of 7A04 high-strength aluminum alloy.

The mechanical properties of aluminum alloy at high temperature degrade greatly compared with that at normal temperature. The research on the mechanical properties of

aluminum alloy at high temperature at home and abroad is still in its infancy, and no systematic design and application system of aluminum alloy structure at high temperature has been formed, which hinders the application of high-strength aluminum alloy materials to a certain extent.

In 2011, Zhang Wei et al. [21] studied the quasi-static and dynamic constitutive relations of high-strength aluminum alloy 7A04 from room temperature to 250 °C by using smooth round bar samples, and obtained the relationship between failure strain and stress state of 7A04 by combining torsion and compression tests. Based on the test results, the strain strengthening terms and temperature softening terms in the Johnson-Cook strength model were modified. The results are in good agreement with the test results.

In 2017, in order to evaluate the performance of aluminum alloy structure after fire, Chen Zhihua et al. [22] conducted a single and repeated fire subjected mechanical properties test of 6061-T6 and 7075-T73 aluminum alloys by natural cooling and fire spray cooling respectively, and obtained a calculation formula for the mechanical properties of aluminum alloys after repeated fire based on the test results. The results show that the damage mode of aluminum alloy after fire is mainly related to the grade of aluminum alloy and the fire temperature, while the cooling mode has little effect; 7075-T73 aluminum alloy specimen has no obvious necking phenomenon, showing brittle failure characteristics; 7075-T73 aluminum alloy is more sensitive to fire temperature, after cooling by fire spray, the specimen has higher strength, but the ductility is slightly reduced. In 2019, Guo Xiaonong et al. [23] conducted material mechanical properties tests on 25 7020-T6 aluminum alloy specimens at 11 temperature points ranging from -120 °C to 300 °C under high and low temperature conditions. However, different from the conclusions in the above literature [22], the failure of 7020-T6 aluminum alloy after high temperature showed plastic failure, and the section of the damaged part showed obvious necking phenomenon.

4 Conclusion and prospect

The research on 7 series high-strength aluminum alloy mainly focuses on the mechanical properties of the material, and the research on the axial compression stability and local stability of its components is still in the preliminary stage. The overall stability of bending resistance and the stability of bending need further research. In the future, through the test and large-scale parameter analysis, proposed 7A04 and 7075 and other high-strength aluminum alloy column, beam bearing capacity design methods, to provide technical support for the preparation of specifications.

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