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State-of-the-arts of Research on Fire Protection Technology for Aluminum Alloy Structures in Buildings

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Abstract. This article systematically summarizes and analyzes the research status of critical failure temperature and fire protection technology of aluminum alloy structures, aiming at the problem of poor fire resistance performance of building aluminum alloy structures. It proposes to determine the critical failure temperature of aluminum alloy structures through simulation and experiment combined with specific application scenarios, and to develop inspection and testing methods for special fire protection materials for aluminum alloy structures and technical standards for fire protection technology application. These suggestions provide reference and basis for the research and application of fire protection technology for aluminum alloy structures.

Keywords: Aluminum Alloy Structures; Fire Protection; Critical Failure Temperature

1 Introduction

Aluminum alloy material has a density only one-third of that of iron, and has the advantages of lightweight and high strength. It can form a stable oxide film in the atmosphere, has good weather resistance, and can be extruded, recycled, easy to maintain, and easy to construct. It is widely used in various fields such as aerospace and transportation, and its application in building structures is becoming increasingly widespread. Aluminum alloy materials are commonly used in building structures, including curtain wall profiles, large metal roof panels, pedestrian bridges, portal frames, spatial grid structures, communication towers, and low-rise frame structures[1], as shown in Figure 1. Among them, the application of aluminum alloy spatial grid structures is more common. Since the 1990s, China has built dozens of aluminum alloy spatial grid structure buildings, such as the Chengdu Pixian Sports Center built in 2018. In recent years, some domestic enterprises have also developed prefabricated aluminum alloy structural houses using aluminum alloy as the main material. The aluminum alloy structural houses are composed of components such as walls, roofs, floors, stairs, etc., and each

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component can be modularized and assembled, and the whole house can be prefabricated in the factory. Obviously, aluminum alloy structures have a very broad application prospect and development space.

Aluminum alloy structures are increasingly being used in various fields of construction engineering due to their unique advantages, but their poor fire resistance is also a problem worthy of our attention. The mechanical properties of metal materials vary greatly between room temperature and high temperature. As shown in Figure 2, When the temperature reaches 400°C, the strength of the steel gradually decreases; When the temperature reaches 600°C, the strength decreases to below 50% of that at room temperature. Compared to steel, aluminum alloy has poorer fire resistance. When the temperature rises, the strength and elastic modulus of aluminum alloy materials decrease rapidly. At 200°C, the strength of structural aluminum alloys begins to significantly decrease; At 300°C, the strength decreases to below 50% of the strength at room temperature; When the temperature reaches 550°C, the strength and elastic modulus of the aluminum alloy material used in the structure are basically lost [2-3]. In the figure, steel-f_y is the yield strength of steel, al-$f_{0.2}$ is the nominal yield strength of aluminum alloy, steel-E and al-E are the elastic moduli of steel and aluminum alloy, respectively, and k is the ratio of material performance parameters at high temperature to room temperature.

(a) Pedestrian Overpass (b) Houses

(c) Comprehensive Gymnasium (d)Villa

Fig. 1. Typical aluminum alloy structure building

In the event of a fire, the temperature at the fire site can generally reach over 800°C. Therefore, once a fire occurs in an aluminum alloy structure building, its load-bearing capacity gradually decreases with the increase of temperature, and the deflection of the structure increases. It is likely that the aluminum alloy structural components will reach buckling in a short period of time, causing damage or even collapse of the entire structure.

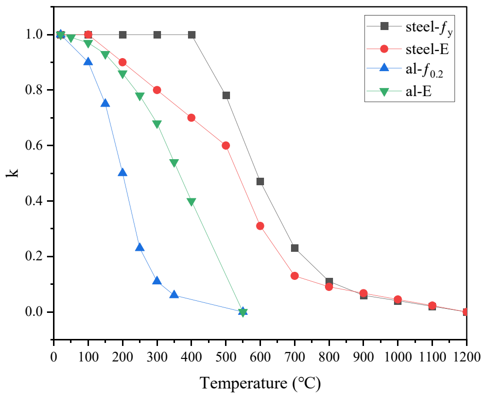


Fig. 2. Material properties of steel and 6061-T6 aluminum alloy under high temperature conditions in European standards

Fig. 3. Jesus Dome Fire

There have been relevant fire cases both domestically and internationally. According to reports, on June 7, 2016, the Jesus Dome church at Durban Christian Centre in South Africa caught fire due to an electrical malfunction, causing the dome to collapse and more than 5500 seats to be burned. And the church was built in 1999, reportedly the second largest aluminum alloy structure building in the southern hemisphere. After the fire, the aluminum alloy dome collapsed before the fire department arrived, as shown in Figure 3. Obviously, the fire resistance of aluminum alloy structures is extremely poor. Therefore, it is necessary to carry out fire resistance design for aluminum alloy structures and take effective fire protection measures.

Many scholars at home and abroad have conducted research on the fire resistance of aluminum alloy structures. Khalifa, Kaufman, and Maljaars conducted tensile and bending tests on aluminum alloy materials, and proposed formulas for the properties of aluminum alloy high-temperature materials based on the test results [4]. Guo,X.et al. [5] have completed the research on 6061-T6 for domestic structural use Study on High Temperature Properties of 6082-T6, 6N01-T6, 6061-T4 Aluminum Alloys. Chen,Z. ,et al. [6-7] conducted single and repeated fire tests on the mechanical properties of 6061-T6 and 7075-T73 aluminum alloys used in construction. Yin,L.,et al. [8] conducted tensile and creep tests on 6061-T6 aluminum at room temperature and high temperature, and proposed a three-stage reduction coefficient model for high-temperature material properties (elastic modulus, specified plastic elongation strength, tensile strength), a constitutive model for ultimate limit state of bearing capacity, and a creep rate model for the second stage. Sun,Y. and Han,Q., et al.[9-11] studied the behavior of different forms of specimens, such as aluminum alloy H-section short columns, aluminum alloy plates, and aluminum alloy square hollow profiles, in a fire. Guo,X.[12], Wang,Z. [13], et al. have summarized the relevant research on the fire resistance performance of aluminum alloy structures, but mainly focused on the performance of aluminum alloy materials under high temperature conditions, with less attention paid to fire protection technical measures for aluminum alloy structures.

However, relevant research and summaries mainly focus on the performance of aluminum alloy materials under high temperature conditions, the fire resistance design methods of aluminum alloy structures, etc. There is relatively little content related to the critical failure temperature of aluminum alloy structures and specific fire prevention technologies. Therefore, this article will systematically review and summarize the critical failure temperature of aluminum alloy structures and specific fire prevention technologies, in order to assist the development of aluminum alloy structures.

2 Critical Failure Temperature of Aluminum Alloy Structures

The research on fire protection technology for aluminum alloy structures first requires determining the critical failure temperature of the aluminum alloy structure. This chapter summarizes the foreign regulations on the critical failure temperature of aluminum alloy structures through literature research, as shown in Table 1[2, 14-16]. The European Code (Eurocode 9-Part 1-2) [2] specifies a critical failure temperature of 170°C for aluminum alloy structures, while the American Aluminum Alloy Design Manual [14] cites

Kaufman's research results and believes that the failure temperature of aluminum alloy structures is between 190°Cand 260°C. The critical temperature to ensure that the yield strength is equal to the design allowable stress is about 260°C, and the critical temperature to ensure that the performance of aluminum alloys at room temperature does not undergo significant changes due to heating is 190°C. In addition, the American Aluminum Alloy Design Manual also provides the high temperature resistance limit of some grades of aluminum alloys, as shown in Table 2.

In addition, some scholars have studied the fire resistance performance of aluminum alloy structures through component fire resistance tests or building fire tests. Liu,S. ,et al. [17] conducted fire resistance tests on aluminum alloy I-beams (H350×140×10×6), using a large space heating curve (such as Figure 4) and applying a uniformly distributed load of 108KN. When the internal temperature of the aluminum alloy I-beam reaches 300°C or the mid span deflection reaches 40mm, the deformation of the beam will increase sharply and reach the failure limit in a short period of time (such as Figure 5).

Table 1. Critical failure temperature of aluminum alloys in some articles or standards

Institutions or experts	Standard or article	Specific requirement
International Maritime Organization (IMO)	Code of Safety for High Speed Craft, HSC Code	The temperature rise of aluminum alloy in standard fire test shall not exceed 200 °C
U.S. Coast Guard	Navigation and Vessel Inspection Circulars 9-97	The temperature rise of aluminum alloy in standard fire test shall not exceed 200 °C
Transport Canada，Marine Safety Directorate	Guide to Structural Fire Protection (TP 11469 E) Section 4.8.1	The core temperature of aluminum alloy components in standard fire tests shall not exceed 200 °C
Kaufman and Kasser	Kaufman, J. and Kasser, R., 1963, “Fire Protection for Aluminum Alloy Structural Shapes,” Civil Engineering, pp.46-47.	The failure temperature is between 190 °C and 260 °C; a) Ensure that the yield strength is equal to the design allowable stress (~260 °C), b) Ensure that the performance of aluminum alloy at room temperature does not undergo significant changes due to heating (190 °C)
CEN	Eurocode 9 Design of aluminum structures- Part 1-2:Structural fire design	The critical failure temperature is 170 °C
American Aluminum Association	Aluminum Design Manual	The high temperature resistance limit of some grades of aluminum alloys has been determined (see Table 2)

Maljaars	Maljaars, J., Soetens, F., and Katgerman, L., 2008, "Constitutive Model for Aluminum Alloys Exposed to Fire Conditions," Metallurgical and Materials Transactions A, Vol.39A, pp.778-789.	The critical failure temperature ranges from 170 °C to 375 °C and depends on the applied stress level
Suzuki	Suzuki, J., Ohmiya, Y., Wakamatsu, T., Harada, K., Yuasa, S., and Kohno, M., 2005,"Evaluation of Fire Resistance of Aluminum Alloy Members," Fire Science and Technology," Vol. 24, pp.237-255.	The critical failure temperature is 250-450 °C, which depends on the type of aluminum alloy, external stress, aspect ratio, etc
Fogle E J	Fogle E J, Lattimer B Y, Feih S, et al. Compression load failure of aluminum plates due to fire[J]. Engineering Structures, 2012, 34(1):155-162.	The critical failure temperature is between 100-480 °C and depends on the applied stress and the type of aluminum alloy

Table **2.** The high temperature resistance limit of aluminum alloys specified in the Aluminum Design Manual of American

Temperature (T)		Time (t)
/°F	/°C	
450	230	5min
425	220	15min
400	205	30min
375	190	2h
350	175	10h
325	165	100h
300	150	1000h
212	100	100000h

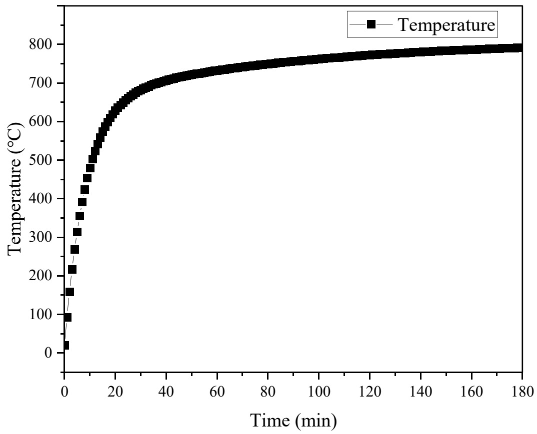


Fig. 4. Heating curve of large space fire

(a) Before the experiment (b) After the experiment

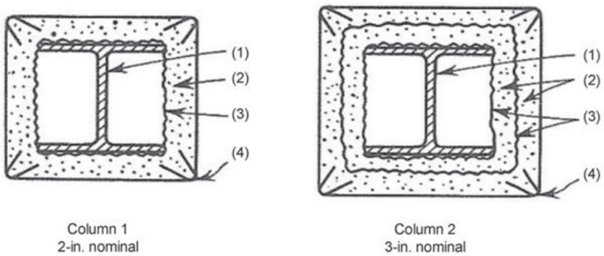
Fig. 5. Aluminum alloy I-beam before and after fire resistance test

Yin, L., et al. [18] conducted simulated fire experiments using a cylindrical aluminum alloy mesh roof system model to verify the reliability of the critical temperature of 150 °C commonly used in aluminum alloy structural fire protection design. The results indicated that although 150 °C is a large safety margin, it may limit architectural function. Guo,X.,et al. [19-20] conducted a scaled aluminum alloy mesh shell structure fire test using an oil pool fire. The results showed that when the fire source power was 2 MW (corresponding to the prototype fire source power of 110 MW) and burned on the ground, the deformation generated by the aluminum alloy mesh shell model was restored after the test, and no permanent deformation affecting the macroscopic bearing performance of the structure was observed. In order to simulate a local high-power fire scenario, the same power fire source was raised by 1.35 meters and tested again. The mesh shell model collapsed and damaged 528 seconds after the fire source was ignited. Among them, the failure modes include component melting, rod fracture, and torsional instability.

In summary, according to research and regulations at home and abroad, the critical failure temperature of aluminum alloy structures is roughly between 150 °C and 480 °C, and is related to the type of aluminum alloy, load size, section coefficient (aspect ratio), etc.

3 Fire Protection Technology for Aluminum Alloy Structures

Kaufman from the United States introduced the characteristics and fire protection measures of aluminum alloy materials in his book "Fire Resistance of Aluminum and Aluminum Alloys and Measuring the Effects of Fire Exposure on the Properties of Aluminum Alloys" [4]. The main fire protection materials include rock wool, ceramic fiber, calcium silicate board, vermiculite board, gypsum board and other insulation materials, coatings, nano microporous insulation materials, etc. During their work at the Aluminum Company of America, Kaufman and Kasser evaluated the feasibility of using lightweight vermiculite concrete for fire protection in aluminum alloy structures in 1962. The experiment was conducted by UL in the United States. The test specimens are two extruded 2014-T6 aluminum alloy columns, coated with vermiculite concrete with thicknesses of 5.08cm and 7.62cm respectively. According to the standard ASTM E119, the test results are shown in Figure 6 and Figure 7. The aluminum alloy column with a coating thickness of 5.08cm reaches 190°C at 2h13min and 260°C at 2h29min, while the aluminum alloy column with a coating thickness of 7.62cm reaches 190°C at 4h 7min and 260°C at 4h 30min. This study suggests that aluminum alloy components can be protected against fire using methods similar to those used to protect steel structural components, except that the protective layer is relatively thicker.



(1-aluminum alloy column, 2-vermiculite concrete, 3-neneneba batten layer, 4-trapezoidal corner bead)

Fig. 6. Cross section of aluminum alloy column specimen

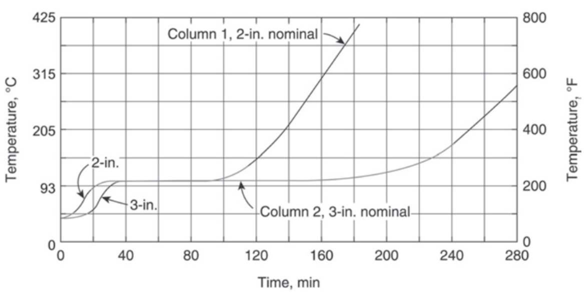


Fig. 7. Temperature rise curve of aluminum alloy column (Column 1, 5.08 cm; Column 2, 7.62 cm)

During the period of 1983 to 1985, the Fire Insurers' Research&Testing Organization (FIRTO) and the Norwegian Fire Research Laboratory conducted fire resistance tests on various structural components on board ships after covering them with rock wool according to the standard BS 476-7. The typical encapsulation method and experimental results are shown in Figures 8 and 9. As shown in Figure 9, the temperature of the protected aluminum alloy sample in the experiment did not exceed the specified limit temperature (200°C). Therefore, after 1985, Lloyd's Register of Shipping and American Bureau of Shipping began to accept the use of mineral wool (rock wool) partitions for fire protection of aluminum alloy decks and bulkheads on ships.

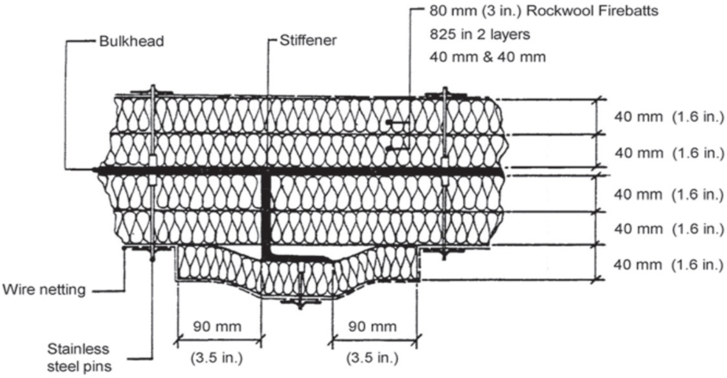


Fig. 8. Schematic diagram of rock wool protection structure

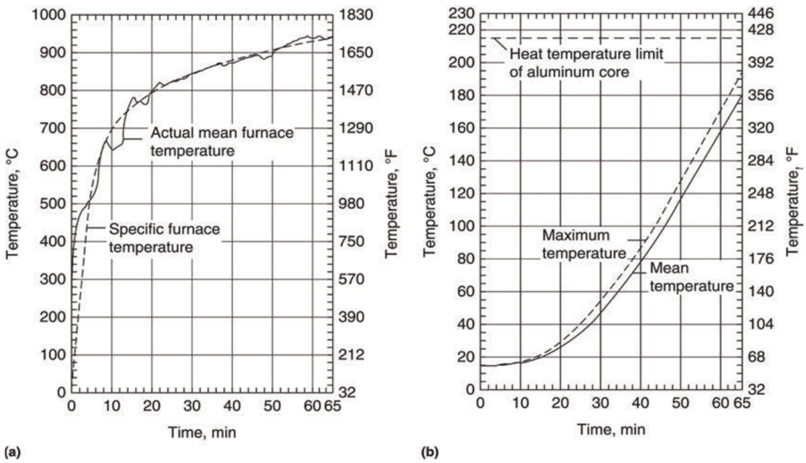


Fig. 9. Temperature rise curve of the experimental furnace (a) and temperature rise curve of the aluminum alloy during the test (b)

In the 1990s, with the support of the COMETT II program of the European Commission, Europe launched a TALAT Project Training in Aluminum Application Technologies, which involved many aspects of fire protection for aluminum alloy structures

[21], mainly including the principles, methods, and fire-resistant materials of fire-resistant design for aluminum alloy structures, and described fire-resistant design methods through case studies. The content mentioned in Kaufman's monograph on fire protection methods and materials for aluminum alloy structures mainly refers to the relevant content of TALAT cited.

The Basic Law of Architecture, published in Japan in May 2002, recognized the legality of aluminum alloy as a building structural material. Afterwards, many Japanese scholars conducted research on the fire resistance performance and fire protection technology of aluminum alloy structures. Suzuki et al. [15] conducted an evaluation of the fire resistance performance of aluminum alloy components. They conducted a series of fire resistance tests on aluminum alloy columns (A5083-O, A5083-H112) and beams (A5083-H112) using a fire resistance test horizontal furnace. The temperature rise inside the furnace met the standard heating curve specified in ISO 834, and considered the effects of applied load, no load, aluminum alloy profile section coefficient, fire protection measures (different calcium silicate plates), and other different situations on the fire resistance performance of aluminum alloy components. The results showed that the critical failure temperature of aluminum alloy components was 250-450°C, which depends on the type of aluminum alloy, external stress, aspect ratio, etc. ARAYA,M. ,et al. [22] conducted research on improving the fire resistance of aluminum alloy pipes, surface materials, and connection parts through water cooling. The results showed that the temperature of aluminum alloy profiles can be controlled by controlling the water flow rate, and the temperature of aluminum alloy profiles can be ensured to be below 200°C in case of fire.

Zheng,Y.,et al. [23] used finite element method to calculate the temperature field of aluminum alloy square tube columns and I-beams without protective layer and with fire protection layer under fire, and compared the calculation results with Eurocode 9 heating formula and experimental results. The research results indicate that for square tube columns without fire protection, the predicted results of Eurocode 9 are too high when the radiation safety factor is 1, while the calculated results of safety factor 0.15 are in good agreement with the measured values and finite element values. For square tube columns with fire protection, the calculated results of Eurocode 9 are very close to the finite element results. Wang,W., et al.[24] used the incremental method to calculate the temperature rise curve of lightweight protective layer aluminum alloy components under ISO 834 standard temperature rise, and conducted nonlinear fitting analysis on the data. They obtained a simplified formula for calculating the temperature rise of lightweight protective layer aluminum alloy components, and then determined the thickness of the fire protection layer based on the critical temperature and fire resistance limit of the aluminum alloy components. Research has shown that under the same heating conditions, aluminum alloy components with the same cross-section have a faster heating rate than steel components. Yan,M.,et al. [25] conducted fire tests on unprotected aluminum alloy components, water filled aluminum alloy components, and water filled aluminum alloy components. The test results show that aluminum alloy hollow components without fire protection have extremely poor fire resistance, and yield in a very short period of time under certain loads; The presence of water can improve the fire resistance of hollow aluminum alloy components and delay their failure time.

The team of the author of this article have developed aluminum alloy structural fire resistive coatings based on the low-temperature and stepwise foaming protection technology of expansion fire resistive coatings (such as Figure 10). The fire resistive coating is composed of ammonium polyphosphate, melamine, pentaerythritol, emulsion, foaming agent, defoamer, functional additives and water in a certain proportion, and is prepared through dispersion, stirring, pH adjustment and other steps. Low decomposition temperature foaming agents, such as AC11, are added to fire resistive coatings. The coating formed by brushing on aluminum alloy profiles can expand and foam to form a carbon layer at lower temperatures after being exposed to fire. A fire resistance test was conducted on an aluminum alloy I-beam (H350 × 140 × 6 × 10) coated with fire resistive coating in accordance with GB14907-2018. The test used the large space fire temperature rise curve shown in Figure 4, and a uniformly distributed load of 40kN was applied to the specimen. The test results showed that the coating thickness was 6mm, and the fire resistance limit could reach 2.36h. At the end of the test, the bending deformation of the aluminum alloy was 30.0mm. We also conducted fire resistance tests on aluminum alloy I-beams (H400×180×8×11) coated with vermiculite based fireproof boards. The main conditions of the test were: the temperature in the test furnace was raised according to the large space fire temperature rise curve shown in Figure 4, and the installation, restraint, and loading of the I-beams were carried out in accordance with the relevant provisions of GB 14907-2018. The uniformly distributed load borne by the I-beams was 187kN, and the thickness of the fireproof board was 25mm. Under the test conditions, the fire resistance limit of the component is 1.48h, and the maximum bending deformation is 126mm (such as Figure 11). In addition, we have also conducted research on water spray protection technology for aluminum alloy truss structures and developed node specific water spray protection nozzles (such as Figure 12). In a 10MW fire, the protected node temperature does not exceed 150°C, which can cover and protect the weakest parts of the aluminum alloy structure.

(a) Before the experiment (b) After the experiment

Fig. 10. Fire resistive coating for Aluminum alloy structure

Fig. 11. Fireproof Board for Aluminum alloy structure

(a) Special spray nozzle and its installation method

(b) Spray effect

Fig. 12. Special spray nozzle for aluminum alloy reticulated shell structure node and its spray effect

In summary, through the review and summarization of relevant research on fire protection technology for aluminum alloy structures at home and abroad, it is found that the fire protection measures for aluminum alloy structures are similar to those for steel structures, mainly including fire resistive coatings, fireproof boards, fireproof cotton, and water cooling. Aluminum alloy structures have received widespread attention and application due to their lightweight and aesthetic appeal. Therefore, when choosing fire protection measures, it is important to consider preserving this advantage as much as possible. Therefore, for building aluminum alloy structures located in relatively concealed areas or with high fire resistance requirements, it is recommended to prioritize the use of fireproof boards and other protective methods. For building aluminum alloy structures with high aesthetic requirements, it is recommended to use fire resistive coatings or water-cooling protection methods, and fire resistive coatings should also have good decorative effects. However, due to the much lower critical failure temperature and significantly different interface characteristics of aluminum alloy structures, corresponding fire protection measures also vary.

4 Conclusions

Overall, although research on fire protection technology for aluminum alloy structures has made some progress compared to steel structures, there are still some shortcomings:

(1) The critical failure temperature of aluminum alloy components and structures is related to the type of aluminum alloy, load size, section coefficient (aspect ratio), heating rate, etc., which are difficult to determine and apply in practical engineering. Therefore, the critical failure temperature of aluminum alloy structures should be determined through a combination of simulation and experimentation based on specific application scenarios, and fire protection measures should be considered.

(2) The fire protection technology for aluminum alloy structures is not yet perfect, and there is a lack of standardized inspection and testing methods for fire-resistant coatings and other products. Fire protection technologies such as water cooling lack application technical standards. Therefore, fire protection design requirements should be clarified in combination with application scenarios, and inspection and testing methods for specialized fire protection materials for aluminum alloy structures and fire protection technology application technical standards should be developed.

(3) Aluminum alloy structures are widely used due to their lightweight and aesthetic appeal. When selecting fire protection measures, attention should be paid to preserving this advantage. Therefore, in the future, research should be conducted to establish a more comprehensive fire performance evaluation system, taking into account fire performance, physical and chemical properties, apparent characteristics, etc., and exploring more efficient fire materials and technologies.

Acknowledgments

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References

1. Zhang,Q. "Applications Researches and Developments of Aluminum Alloy Structures in China," Construction Technology, 47:13–17+25, 2018, DOI: 10.7672/sgjs2018150013.
2. CEN,"Eurocode 9-Design of aluminum structures- Part 1-2: Structural fire design," European Standard EN 1999-1-2:2007, Rev. September.2006.
3. CEN,"Eurocode 3: Design of steel structures - Part 1-2: General rules - Structural fire design," European Standard EN 1993-1-2:2005, Rev. April.2004.
4. Kaufman,J. , "Fire Resistance of Aluminum and Aluminum Alloys and Measuring the Effects of Fire Exposure on the Properties of Aluminum Alloys," ASM International, 2016, United States of America.
5. Guo,X., Gao, Z. and Zhu,S., "Experimental Research on Mechanical Property of Domestic Structural Aluminum Alloy at Elevated Temperatures," Journal of Hunan University (Natural Sciences), 45:25-33,2018, DOI: 10.16339/j.cnki.hdxbzkb.2018.07.003.
6. Chen,Z., Lu,J. and Liu,B., "Experimental investigation on mechanical properties of structural aluminum alloys after single and multiple fire exposure," Journal of Building Structures,38:149-159+174,2017, DOI: 10.14006/j.jzjgxb.2017.04.016.
7. Liu,H., Zhou,Y., Chen,X. and Chen,Z. , "Research on residual mechanical properties of post-fire 6061-T6 aluminum alloy extruded profiles," Spatial Structures,24:75-82,2018, DOI:10.13849/j.issn.1006-6578.2018.03.075.
8. Yin,L., Ni,Z. , Fan,F. and Ye,J. , "Experimental study on mechanical properties of 6061-T6 aluminum alloy. Journal of Building Structures,44:196-206,2023,doi: 10.14006/j.jzjgxb.2022.0049.
9. Sun,Y., Li,M., Chen,X. and Raffoul,S., "Material response and local behaviour of post-fire aluminium alloy square hollow sections," Journal of Constructional Steel Research, 227: 109392,2025, doi: 10.1016/j.jcsr.2025.109392.
10. Sun,Y., Cheng,W. , and Cheng,K. , , "Experimental study of in-fire and post-fire material response of high-strength aluminium alloys," Journal of Building Engineering, 91:109581,2024, DOI: 10.1016/j.jobe.2024.109581.
11. Han,Q., Li,M. ,and Wang,Z., "Testing of high strength aluminium alloy SHS and RHS stub columns in fire," Engineering Structures, 284:115971,2023, doi: 10.1016/j.engstruct.2023.115971.
12. Guo,X., Chen,C., Zhu,S., and Chen,Z., "State-of-the-arts of Research on Fire-resistance of Aluminum Alloy," Journal of Disaster Prevention and Mitigation Engineering, 40:293-308,2020, doi: 10.13409/j.cnki.jdpme.2020.02.020.
13. Wang,Z., Li,M., Han,Q., Yun,X.,et al. , "Structural fire behaviour of aluminium alloy structures: Review and outlook," Engineering Structures, 268:114746, 2022, doi:10.1016/j.engstruct.2022.114746.
14. Dolby T , "Aluminum Design Manual 2020," The Aluminum Association, Rev.2004.
15. Suzuki,J., Ohmiya,Y., Wakamatsu,T., Harada K, et al. , " Evaluation of Fire Resistance of Aluminum Alloy Members," Fire Science and Technology, 24:237-255,2005,doi: 10.3210/fst.24.237.
16. Fogle,E., Lattimer,B., Feih,S., Kandare,E., et al. , " Compression load failure of aluminum plates due to fire," Engineering Structures, 34:155-162,2012,doi: 10.1016/j.engstruct.2011.09.014.
17. Liu,S. and Wang,S., "Comparison of bearing capacity and fire resistance performance of two types of structural I-beams," Fire Science and Technology(supplement),39:94-96, 2020.

18. Yin,L., Ni,Z., Fan,F., Qiu,P., Kan Q , et al. , "Temperature field characteristics of cylindrical aluminum alloy reticulated roof system under localized fire," Fire Safety Journal, 121: 103267,2021,doi: 10.1016/j.firesaf.2020.103267.
19. Guo,X., Chen,C., Zhu,S.and Jiang,S., " Nondestructive experimental study on fire response of aluminum alloy reticulated shells with gusset joints," Journal of Building Structures,42:72-84,2021,doi: 10.14006/j.jzjgxb.2019.0814.
20. Guo X., Chen,C., Zhu,S.and Jiang,S., "Destructive fire tests on aluminum alloy reticulated shells with gusset joints," Journal of Building Structures, 42:72-81, 2021, doi: 10.14006/j.jzjgxb.2019.0815.
21. Ostermann,F., "TALAT - a training programme for aluminium application technologies in Europe," Materials Science and Engineering A, 199:73-77,1995, doi:10.1016/0921-5093(95)09911-5.
22. ARAYA,M., "Study on aluminum structure's fire proof capability by utilizing water-cooling system: Part1 Application to beam member,"Summary of Academic Speeches at the Japan Architecture Society Conference, 227-228,2009.
23. Zheng,Y. and Zhang,Z. , "The fire performance and fire-resistance design of aluminium alloy I-beams," Fire and Materials, 40:141-157,2016,doi: 10.1002/fam.2275.
24. Wang,W., Ding,Y., Zhang,Z.and Yan,M., "A simplified method for calculating temperature of aluminum alloy components with light fire protection. Fire Science and Technology, 40:33-37,2021,doi: 10.3969/j.issn.1009-0029.2021.01.009.
25. Yan,M. and Zhang,Z., "Experimental study on fire resistance performance of hollow water-filling aluminum alloy member," Building Structure, 51:55-59,2021,doi: 10.19701/j.jzjg.2021.20.010.