Study on out-of-plane flexural behavior of aluminum alloy gusset joints at elevated temperatures

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1. Introduction

The future of aluminum alloy spatial structures is promising owing to its lightness, favorable appearance and ease of construction. Aluminum alloy gusset (AAG) joint is a kind of the most widely applied joint system in aluminum alloy reticulated shells, and the elevated-temperature mechanical behavior of joints have serious influence on the safety of structures. This paper investigated the out-of-plane flexural behavior of AAG joint by means of experimental and numerical analysis, and theoretical formulae of its bearing capacity and bending stiffness were derived. Firstly, elevated-temperature experiments on 9 AAG joints were conducted in a special-shaped oven. The test results revealed that: (1) the failure modes of thin-plate AAG joints at temperatures under 300 °C are block tearing and local buckling of the gusset plate, which remain the same as those at room temperature; (2) when the gusset plate is thick enough (usually as thick or thicker than the flange of the member), the joint zone will not collapse under 300 °C; (3) the initial stiffness approximately remains unvaried, while the ultimate flexural bearing capacity drops with the elevation of temperature. Subsequently, finite element (FE) models using ABAQUS were established and verified by the test results. It is confirmed that the FE models can accurately describe the mechanical performance of the AAG joints at elevated temperatures. Based on the simplified FE model, a parametric study was carried out, considering various aluminum alloy brands, thickness of the gusset plate, radius of the center region of the gusset plate and different temperatures. Finally, the block tearing resistance, the local buckling resistance, and parameters of four-linear bending stiffness model of the FE models were presented, and the theoretical formulae were derived using statistical regression technology. The theoretical formulae were verified to be accurate enough against the experimental and FE results, to estimate the bearing capacity and the non-linear bending stiffness of AAG joints at elevated temperatures under 300 °C, which can serve for practical engineering.

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Aluminum alloy gusset (AAG) joint is the most widely applied joint system in aluminum alloy reticulated shells, and the elevated-temperature mechanical behavior of joints have serious influence on the safety of structures. This paper investigated the out-of-plane flexural behavior of AAG joint by means of experimental and numerical analysis, and theoretical formulae of its bearing capacity and bending stiffness were derived. Firstly, elevated-temperature experiments on 9 AAG joints were conducted in a special-shaped oven. The test results revealed that: (1) the failure modes of thin-plate AAG joints at temperatures under 300 °C are block tearing and local buckling of the gusset plate, which remain the same as those at room temperature; (2) when the gusset plate is thick enough (usually as thick or thicker than the flange of the member), the joint zone will not collapse under 300 °C; (3) the initial stiffness approximately remains unvaried, while the ultimate flexural bearing capacity drops with the elevation of temperature. Subsequently, finite element (FE) models using ABAQUS were established and verified by the test results. It is confirmed that the FE models can accurately describe the mechanical performance of the AAG joints at elevated temperatures. Based on the simplified FE model, a parametric study was carried out, considering various aluminum alloy brands, thickness of the gusset plate, radius of the center region of the gusset plate and different temperatures. Finally, the block tearing resistance, the local buckling resistance, and parameters of four-linear bending stiffness model of the FE models were presented, and the theoretical formulae were derived using statistical regression technology. The theoretical formulae were verified to be accurate enough against the experimental and FE results, to estimate the bearing capacity and the non-linear bending stiffness of AAG joints at elevated temperatures under 300 °C, which can serve for practical engineering.
degradation of the material was proposed. The simplified model greatly shortened the time of practical design. For tubular joints, Feng [6] carried out a great deal of parametric study using finite element (FE) models of X- and T- tubular joints, and improved the existing formulae of bearing capacity by introducing the influence of the temperature correction coefficient. Based on reliability analysis, it is proposed that the low-limit of the bearing capacity can be obtained by multiplying the reduction factor 0.65. Similarly, Ozyurt [7] emphasized that the existing design formulae can be unsafe under particular circumstances. It was suggested that for circular hollow section (CHS) T-, Y- and X-joints under brace compression load, a reduction factor of elastic modulus of steel should be considered, besides the reduction on strength under elevated temperatures. Some methods to improve the fire performance of the joints are also available, Chen [8] introduced internal ring-stiffeners in CHS T-joints. Experimental study and numerical analysis were used to investigate its fire resistance. The experimental results revealed that the internal ring-stiffeners can effectively prolong the fire-resistance time, while the numerical analysis discussed the impact of geometric dimensions on the failure modes under fire conditions. From the aforementioned research results, it can be indicated that the investigation on elevated-temperature performance of the joints should serve for improving the fire design methods of the joints.

AAG joint is a kind of joint connecting I-shaped members with two gusset plates and several stainless steel bolts. Research on the mechanical behavior of AAG joints are mainly at room temperature. Guo [9] finished out-of-plane bending tests on 14 AAG joints. The main failure modes include member rupture, block tearing and local buckling of the gusset plate, and it was verified that the AAG joint is a typical semi-rigid joint. Subsequently, the authors established reliable FE models whose results agreed well with the experimental results. Through theoretical analysis and FE simulation, the formulae to calculate the capacity of block tearing and local buckling of the gusset plate were derived, together with the practical design method to avoid these two failure modes [10]. Based on the component method and statistical regression method, a four-linear out-of-plane bending stiffness model was proposed, and agreed well with the experimental results [11].

Research results on AAG joints at room temperature are relatively rich, while the results at elevated temperatures are relatively scarce. Only Wang [12] summarized the influence of temperature on the failure modes, the ultimate bearing capacity, and the moment-rotation curves of AAG joints. In order to resolve the aforementioned research limitations, this paper focuses on the out-of-plane flexural behavior of AAG joints at elevated temperatures. Tests on 9 AAG joint specimens under various temperatures are conducted. Firstly, the test program is introduced. Secondly, the failure modes, reduction factors of ultimate moment and initial stiffness of the specimens are analyzed. Subsequently, FE models are established and verified against the test results. Finally, based on the reliable FE models, a parametric study is carried out considering various aluminum alloy brands, thickness of the gusset plate, radius of the center region of the gusset plate and different temperatures, and the theoretical formulae estimating the bearing capacity and the nonlinear bending stiffness at elevated temperatures are derived using statistical regression method.

2. Test program

2.1. Specimens

A series of experiments on 9 AAG joint specimens under various temperatures were performed. Each AAG joint specimens connect 6 I-shaped members, and the angle between adjacent members is 60°, as shown in Fig. 1. The members are labelled as L1–L6, and each member is connected by 8 stainless steel M6 bolts hand tightened in 6.5 mm drilled holes, as plotted in Fig. 2.

All the I-shaped members have the same cross-sectional dimensions of H100 × 50 × 4 × 5, (the height of the section is 100 mm, the width of the flange is 50 mm, the thickness of the web and the flange is 4 mm and 5 mm, respectively). The length of the members is 905 mm, and the diameter of the gusset plate is 240 mm. The detailed drawings of the member and the gusset are shown in Figs. 3 and 4. Three varying parameters were considered. The first parameter was the thickness of the gusset plate. Three specimens were classified into the thick plate (plate thickness $t = 4$ mm) category, while six specimens...