Thin-Walled Structures 119 (2017) 58–71

Contents lists available at ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

Full length article

Experimental, theoretical and numerical analysis of K-joint made of CHS aluminium profiles

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ARTICLE INFO

Keywords:
K-joints
Design resistance
Aluminium alloys
Heat affected zone (HAZ)
Circular hollow section (CHS)
Finite element analysis

ABSTRACT

K-joints of welded aluminium lattice structure made of circular hollow section (CHS) profiles are analysed. Aluminium alloy EN AW 6082 T6 was used.

The paper topic is determination of design resistance of K-joint in aluminium lattice structure. Change of mechanical properties of material in welding zones due to high temperatures is important characteristic of aluminium. Level and manner of influence of aluminium softening in zone of welded joint on design joint resistance have been analysed in paper.

Theoretical, experimental and numerical analysis by means of finite elements method (FEM) with 12 specimens of K-joint have been done. European Standard for aluminium structures EN 1999 does not define design resistance of joint in welded aluminium lattice structures. Therefore expressions from standard for steel structures were used. The aim of the paper was to investigate up to which level expressions from EN 1993-1-8 for design resistance of K-joints in welded steel lattice structure may be used for aluminium alloys structures, having in mind change of material properties in welded joints. After comparative analysis, correction and upgrade of expressions from steel structures standard have been proposed, in order to enable their implementation for determination of design resistance of K-joints in aluminium lattice structures.

1. Introduction

Aluminium is a light material, with density of about one third of steel density. Its low weight reduces costs of work, transport and assembling. That increases economic profitability of aluminium alloys structures. Aluminium is used when its favourable characteristics (low weight, corrosion resistance, choice of most suitable shapes during extrusion) provide an advantage over concurrent materials, Mazzolani [1]. Aluminium drawbacks are: low modulus of elasticity (about one third of steel modulus of elasticity) which contributes to its raised deformability, high level of heat conductivity and production price.

In engineering practice, aluminium is used for antenna towers, industrial buildings, bridges, overhead electrical line towers, long span domes, structures in areas with extremely low temperatures etc. Application of aluminium lattice structures is popular in contemporary structural solutions, primarily in transportable structures (such as stages) as well as in overhead electrical line towers. Structures of concert stages and lightening towers are mostly typified and made of aluminium lattice structures. Their advantage is low weight of structure, low costs of maintenance and transport, as well as fast assembling.

Lattice structures consist of chords and brace members which are mainly loaded centrically, by axial compression or tension forces. Determination of design resistance of members of lattice structure made of welded aluminium hollow profiles assumes members resistance control in the following design situations:

- determination of compressed members design resistance by taking into account member buckling,
- determination of compressed members design resistance by taking into account HAZ (heat affected zone),
- determination of tensioned members design resistance out of heat affected zone,
- determination of tensioned members design resistance by taking into account HAZ,
- determination of welded connections design resistance,
- determination of joints design resistance.

Design calculation of aluminium structures is defined by European Standard EN 1999. Calculation principle is based on principles of steel structures calculation. The first five controls are defined by standard EN

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http://dx.doi.org/10.1016/j.tws.2017.05.016
Received 31 December 2016; Received in revised form 11 May 2017; Accepted 12 May 2017
0263-8231/

Nomenclature

A	cross sectional area
A_0	cross sectional area of chord
A_{eff}	effective area of cross section
A^*	area of softening zone (HAZ) in chord cross section
b_{haz}	extent of HAZ
d_0	chord profile diameter
d_1, d_2	brace member profile diameter
e	joint eccentricity
E	Young's modulus of elasticity
$f_{1\%}$	static 1% tensile proof stress – engineering stress
$f_{1\%,true}$	static 1% tensile proof stress – true stress
$f_{3\%}$	static 3% tensile proof stress – engineering stress
$f_{3\%,true}$	static 3% tensile proof stress – true stress
f_o	0,2% proof strength (EN1999-1-1) – engineering stress
$f_{o,EN}$	0,2% proof strength of alloy EN 6082 T6, according to EN 1999-1-1
$f_{o,true}$	0,2% proof strength (EN1999-1-1) – true stress
$f_{o,haz}$	0,2% proof strength in heat affected zone (HAZ) – engineering stress
$f_{o,haz,true}$	0,2% proof strength in heat affected zone (HAZ)– true stress
$f_{o0,red}$	average value of yield strength in partially softened cross section
f_{o0}	0,2% proof strength of chord member
$f_{o0,haz}$	0,2% proof strength in heat affected zone (HAZ) of chord member
f_u	ultimate tensile strength (EN1999-1-1) – engineering stress
$f_{u,true}$	ultimate tensile strength (EN1999-1-1) – true stress
$f_{u,haz}$	ultimate tensile strength in heat affected zone (HAZ) – engineering stress
$f_{u,haz,true}$	ultimate tensile strength in heat affected zone (HAZ) – true stress
f_y	yield strength (EN1993-1-8)
f_{y0}	chord yield strength (EN1993-1-8)
$f_{y0,haz}$	chord yield strength in heat affected zone (HAZ)
g	gap
HV	Vickers hardness
HV_{av}	average Vickers hardness
k_{al}	aluminium softening reduction coefficient
$k_{al,EN}$	aluminium softening reduction coefficient for alloy EN 6082 T6, according to EN 1999-1-1
k_g	joint geometry factor
k_p	chord stress factor
l	length of circular arch in chord cross section below brace member
L	circumference of chord profile cross section
L^*	length of softening zone (HAZ)
n_p	ratio $(\sigma_{p,Ed}/f_{y0})/\gamma_{M5}$
$N_{0,Ed}$	chord load
$N_{1,Rd,AL}$	design resistance determined by means of k_{al}
$N_{1,Rd,AL,EN}$	design resistance determined by means of $k_{al,EN}$
$N_{1,Rd,EKS}$	experimentally determined joint resistance
$N_{1,Rd,EKS,1\%}$	experimentally determined joint resistance at deformation of $1\%d_0$
$N_{1,Rd,EKS,ult}$	experimentally determined ultimate joint resistance
$N_{1,Rd,EN}$	design resistance for aluminium alloy EN 6082 T6, according to EN 1999-1-1
$N_{1,Rd,FEM}$	numerically determined joint resistance
$N_{1,Rd,FEM,1\%}$	numerically determined joint resistance at deformation of $1\%d_0$
$N_{1,Rd,FEM,3\%}$	numerically determined joint resistance at deformation of $3\%d_0$
$N_{b,Rd}$	design buckling resistance of compressed member
$N_{i,Ed}$	design value of the internal axial force in brace member i (i = 1 or 2)
$N_{i,Rd}$	design value of joint resistance, expressed in terms of internal axial force in brace member i (i = 1 or 2)
$N_{i,Rd,haz}$	design value of joint resistance considering HAZ (i = 1 or 2)
$N_{p,Ed}$	chord pre-load
N_{Rd}	design value of the resistance to normal forces
t_0	chord profile wall thickness
t_1, t_2	brace profile wall thickness
γ_{M1}, γ_{M2}	partial safety factors for resistance of members and cross-sections
γ_{M5}	partial safety factor for resistance of joints in hollow section lattice girder
θ_i	angle between brace member i and chord (i = 1 or 2)
$\rho_{o,haz} = f_{o,haz}/f_o$	ratio between 0,2% proof strength in HAZ and in parent material (strength reduction coefficient)
$\rho_{u,haz} = f_{u,haz}/f_u$	ratio between ultimate strength in HAZ and in parent material (strength reduction coefficient)
χ	reduction factor for flexural buckling
ω_0	factor for cross section with localised weld

1999-1-1 [2] and they depend on type of members connection, members geometry and length. The sixth condition of resistance directly depends on joint kind and type, as well as on characteristics of chord and brace members, i.e. ratio of their cross sections diameters and walls thicknesses. The choice of joint geometry (gap between members and eccentricity of joint connection) is also important for brace member resistance. Determination of joints design resistance in steel lattice structures is defined by standard EN 1993-1-8 [3]. This issue is not defined in standard for aluminium structures.

Since aluminium has high level of heat conductivity, even though its melting point is low (around 660 °C) high amount of heat is necessary for alloy melting. High temperatures annul some of treatments applied in alloy production, leading to the change of aluminium properties in the vicinity of weld. This is manifested by forming zone of decreased aluminium strength in the vicinity of weld – HAZ (Heat Affected Zone). For analysed aluminium alloy EN AW 6082 T6, the local decrease in strength is up to 50%, depending on material thickness and applied welding method.

European Standard for design of aluminium structures EN 1999 does not define calculation procedure for K-joint resistance. Therefore the procedure for determination of design resistance of welded K-joint defined in standard for steel structures [3], based on failure modes in Fig. 1 [5,6], was analysed herein. The main aim of research presented in the paper is to define determination of design resistance of welded aluminium K-joint by modification of expressions given in EN 1993-1-8 [3].

In 12 analysed specimens of K-joint, with the same chord profile, only profiles of brace members and joint eccentricity varied. Aluminium alloy EN AW 6082 T6, having favourable characteristics for production of lattice structure members, was used. This alloy belongs to the class of mid-range-strength aluminium alloys with excellent weldability and corrosion resistance. It has the highest strength among alloys of 6xxx series, particularly in T6 temper.

All 12 specimens are tested experimentally, by loading up to the failure. Testing was done in the laboratory of the Faculty of Civil Engineering, University of Montenegro. Following experimental tests, design resistance of K-joint, based on the expressions from EN 1993-1-8 [3], is analysed. Real mechanical properties of material used in