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Numerical/experimental research on welded joints in aluminium truss girders

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Abstract. Welded joints in a 30 meter span aluminium truss girder were investigated numerically and experimentally. Since aluminium design rules for welded K- and N-joints in CHS truss girders were lacking the joints were checked using steel design rules. Calculations showed that the N-joints were governing for chord and brace sizes. Further numerical analysis on the N-joints using ANSYS 11.0 was carried out. Full scale experimental research was successfully carried out for validation of the numerical calculations. It is concluded that steel design rules predict the failure behavior and failure mode of the considered aluminium N-joints well. However, steel design rules overestimate the failure load by 8% for the truss configurations investigated.

Introduction

Aluminium trusses are widely used in the entertainment industry. The advantage of using aluminium truss elements is the light weight product, which allows for easy assembly and disassembly. Aluminium trusses started out as temporarily adjustable beams; nowadays complete stages are erected, entirely build up from truss elements.

In a study on larger spans of aluminium truss girders optimal dimensions were determined for trusses spanning 30 meters loaded by 1 kN/m [1]. Diameters and thicknesses of braces and chords, as well as height of the truss elements, were optimized for minimum weight using optimal transport sizes of the truss elements as a design criterion (Fig.1). However, larger truss spans indicate for more heavily loaded connections. In the considered CHS truss girders two types of connections can be distinguished: a conically pinned connection between two or three meter truss elements, and welded connections in K- and N-joints between braces and chords. Both connections were investigated further. The research on the pinned connections is described in [2]. This paper focusses on the welded joints.

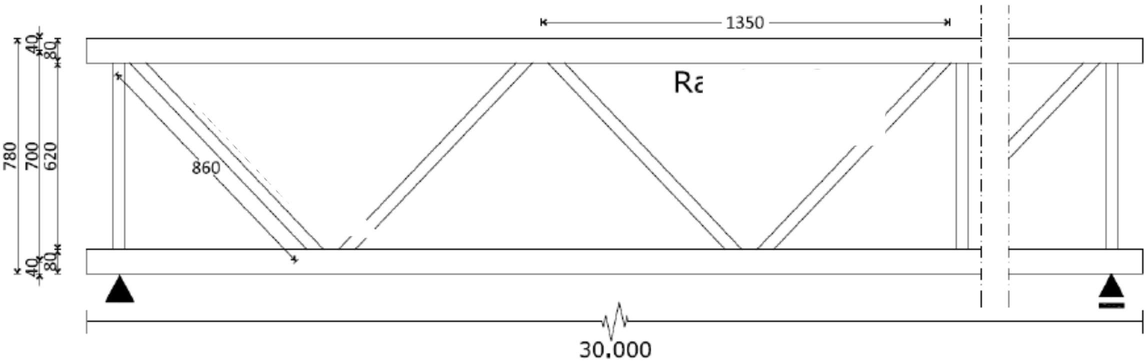


Fig. 1: Aluminium truss optimized for span length 30 meters

Design Rules

Since aluminium design rules for welded K- and N-joints in CHS truss girders are lacking, steel design rules [3] were used. These design rules are similar to the specific design rules in [4], having the same theoretical background i.e. failure criteria and failure modes, such as chord face failure (plastification of chord face or chord cross-section), chord wall failure (yielding or instability), chord shear failure, chord punching shear failure, brace failure (welds or brace members) and local buckling failure.

The material used for chords as well as braces is aluminium alloy 6082 T6. According to table 4 in [5] the design 0.2% proof strength is 250 N/mm^2, according to table 8 in [5] the design tensile strength in the heat affected zone is 160 N/mm^2 using a TIG welding procedure. However, strength properties according to [6] are somewhat different. Table 3.2b in [6] gives a design representative 0.2 % proof strength 250 N/mm^2 for the braces (t = 3 mm) and 260 N/mm^2 for the chords (t = 6 mm). The design strength for tension is 290/1.25 = 232 N/mm^2 in the braces and 310/1.25 = 248 N/mm^2 in the chords. And for compression the design strength is 250/1.10 = 227 N/mm^2 in the braces and 260/1.10 = 236 N/mm^2 in the chords. The design tensile strength in the heat affected zone using TIG is (0.8*185)/1.25 = 118.4 N/mm^2 according to [6]. It can be concluded that design strengths for heat affected zones in Eurocode 9 are far more conservative than in Dutch regulations.

Calculations [1] show that the limited strengths in the heat affected zone of chords and braces in the N-joints at mid span are governing for failure. The maximum tensile stress occurring in this area is 109.9 N/mm^2. The strength limits in this zone have resulted in optimal chord and braces sizes (Fig.2).

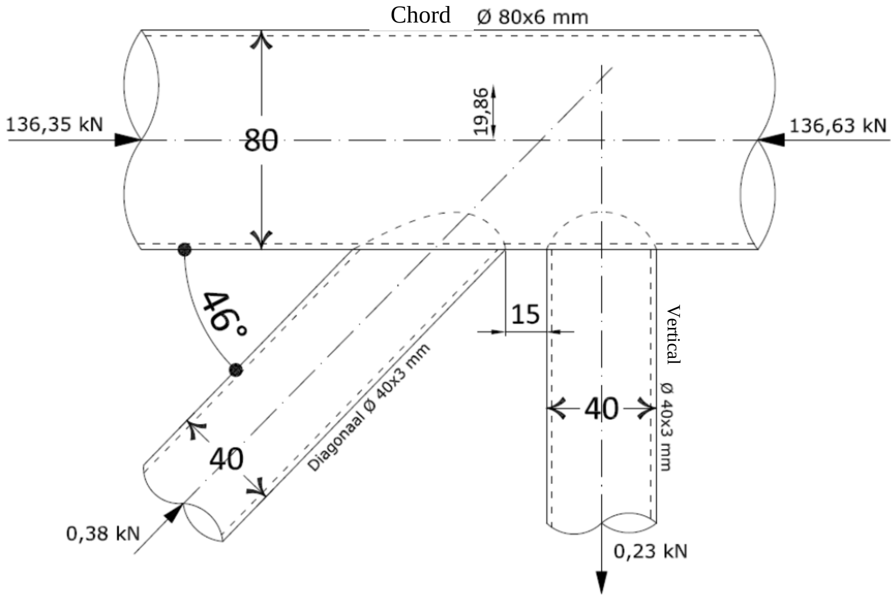


Fig. 2: Truss geometry

Numerical analysis

Numerical analysis using ANSYS 11.0 was carried out to verify the use of steel design rules for aluminium CHS truss girders. External loading on the investigated N-connection was determined using structural engineering software. The resulting loads were checked on equilibrium conditions.

The connection is modelled using shell elements for the aluminium chords and braces and volume elements for the welds (throat thickness 5 mm). Three different non-linear stress-strain curves were used (Fig. 3): one for the parent material (alloy 6082 T6), one for the heat affected zone (TIG welded) and one for the welding material (filler metal 5356). The resulting mesh is shown in Fig. 4. External loads and bending moments are applied using rigid beam elements at the end of each tube (Fig. 5).

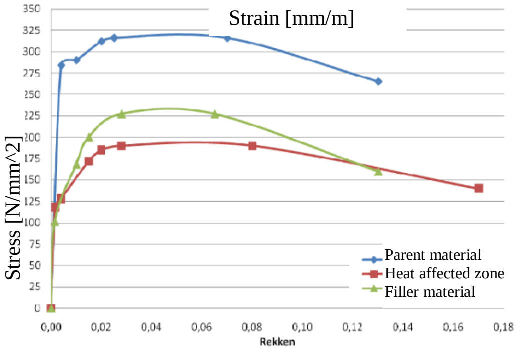


Fig. 3: Stress-strain curves of connection materials

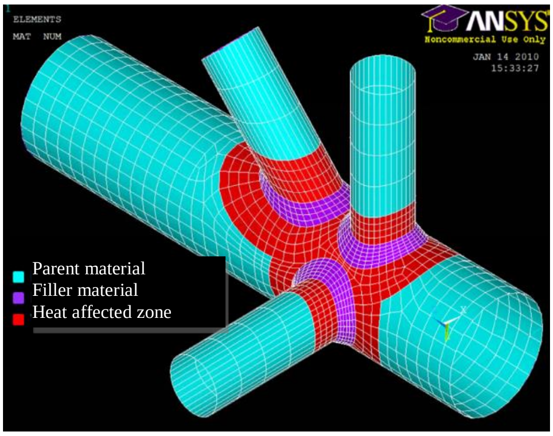


Fig. 4: Connection mesh

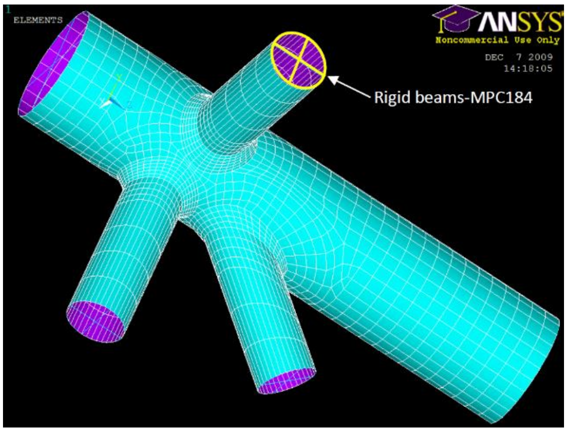


Fig. 5: Rigid beam elements at tube ends

The results of the numerical calculations for chords, braces, heat affected zones and welds are given in [7]. The governing Von Mises stress of 119.0 N/mm^2 is located in the upper layer of the heat affected zone of the transverse brace (Fig. 6 and Fig. 7). The design tensile strength according to [6] is 118.4 N/mm^2. It may be concluded that a 30 meter span truss girder, loaded by 1 kN/m, just fulfils failure criteria when strength properties according to [6] are used.

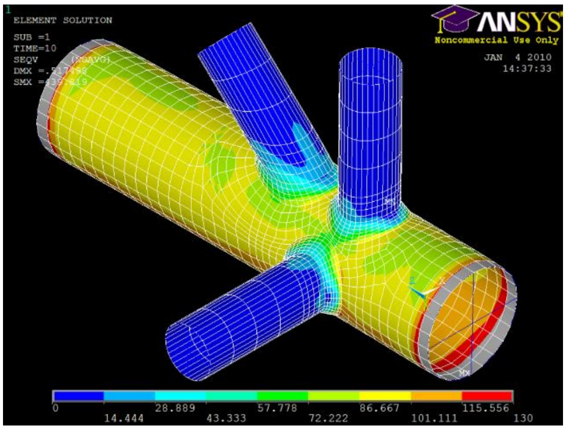
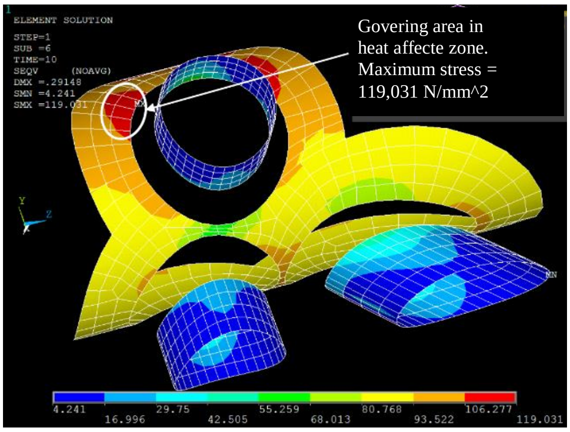


Fig. 6: Surface Von Mises stresses



Govering area in heat affecte zone. Maximum stress = 119,031 N/mm^2

Fig. 7: Von Mises stresses in heat affected zone

Experimental program

A full scale experimental program was carried out for verification of the numerical model. However, the material stresses resulting from the numerical analysis were corresponding to a truss girder spanning 30 meter loaded by 1kN/m. It was impossible to test this span length in the laboratory. Therefore two full scale girders spanning 6 meter were tested, with the N-connection to be investigated as shown in Fig. 8.

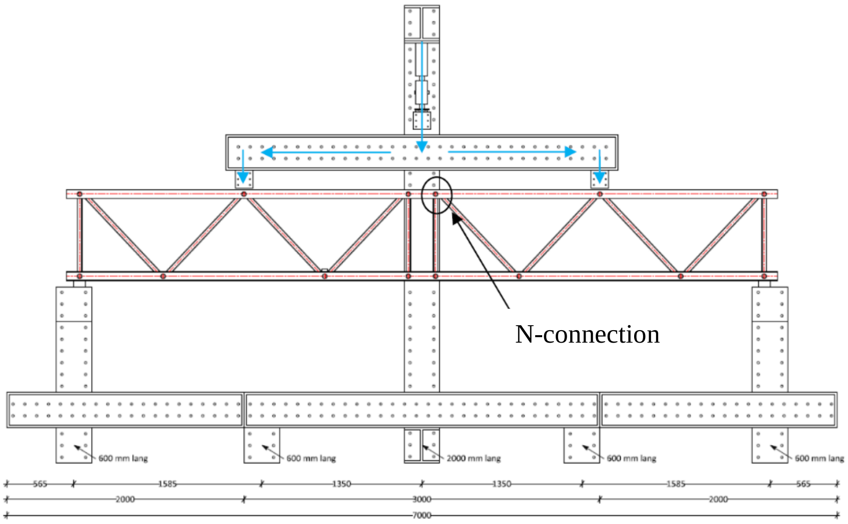


Fig. 8: Testing arrangement

The 6 meter span length automatically consisted of two standard elements of 3 meter. In practice these elements are connected by conical pins. In the test specimens this typical element connection was replaced by continuous CHS chords, because the element connection itself was not subject of investigation.
However, due to the smaller span length the tested truss girder will not fail at midspan, but in the heat affected zone of the diagonal braces near the end supports (Fig. 9 to 11). The mean failure load was 137 kN, representing a uniform distributed load of 23 kN/m, which is of course much higher than 1.0 kN/m for a 30 meter span due to the smaller span length tested.

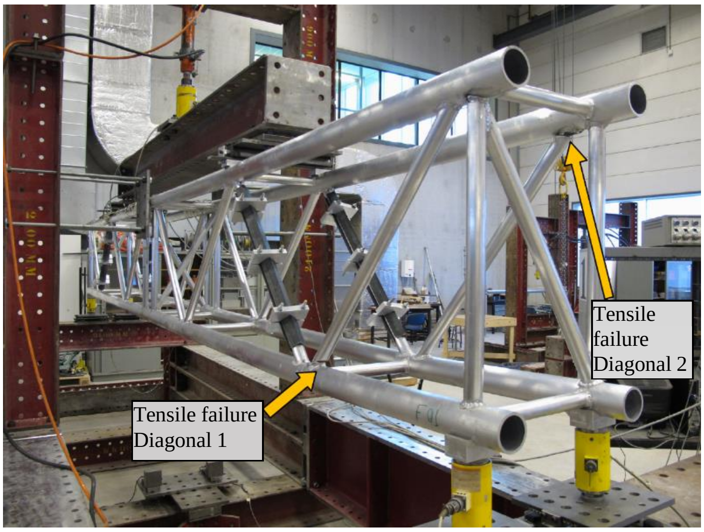


Fig. 9: Failure locations of test specimen 1

Fig. 10: Failure in heat affected zone of diagonal 1

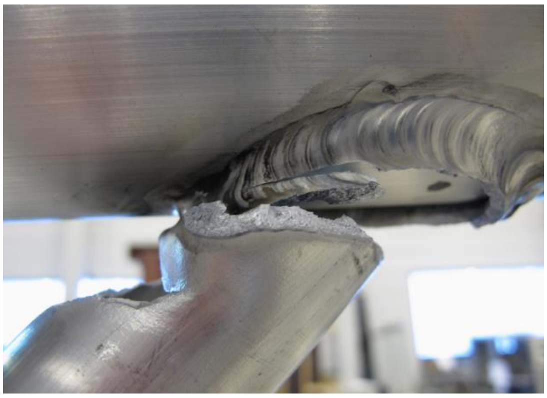


Fig. 11: Failure in heat affected zone of diagonal 2

Strain gauge measurements show that, just before failure, tensile stresses in the heat effected zones of the diagonals reach 173 N/mm^2 in the first test and 164 N/mm^2 in the second test. Compared to the design tensile strength of 160 N/mm^2 the strength properties in [5] may overestimate the strength of heat effected TIG welded zones. However, the design tensile strength in [6] equals 118.4 N/mm^2, which is probably far too conservative when compared to the measured values of 173 N/mm^2 respectively 164 N/mm^2.

The experimental program was aimed to validate the numerical research of the N-joints at mid span. Therefore strain measurements were carried out on the N-joint in the 6 meter specimens (Fig. 12, Fig. 13, Fig. 14). The external loads and moments being different from the engineering model of the 30 meter span girder, were calculated separately (see [7]). New numerical analysis was carried out for this particular loading condition. In table 1 the resulting Von Mises stresses (strain gauge measurements versus ANSYS calculations) are compared.

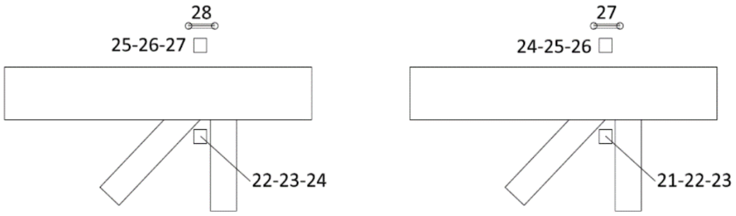


Fig 12: Location of strain gauges in specimen 1 and 2 (side views)

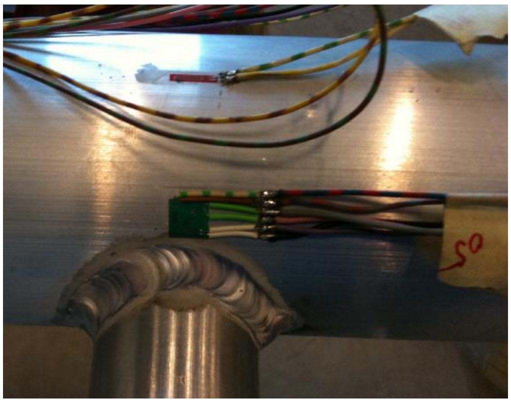


Fig. 13: Strain gauges 25 to 27 (test 1) and 22 to 24 (test 2)

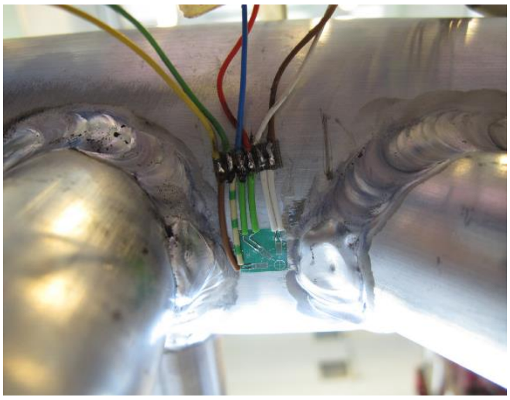
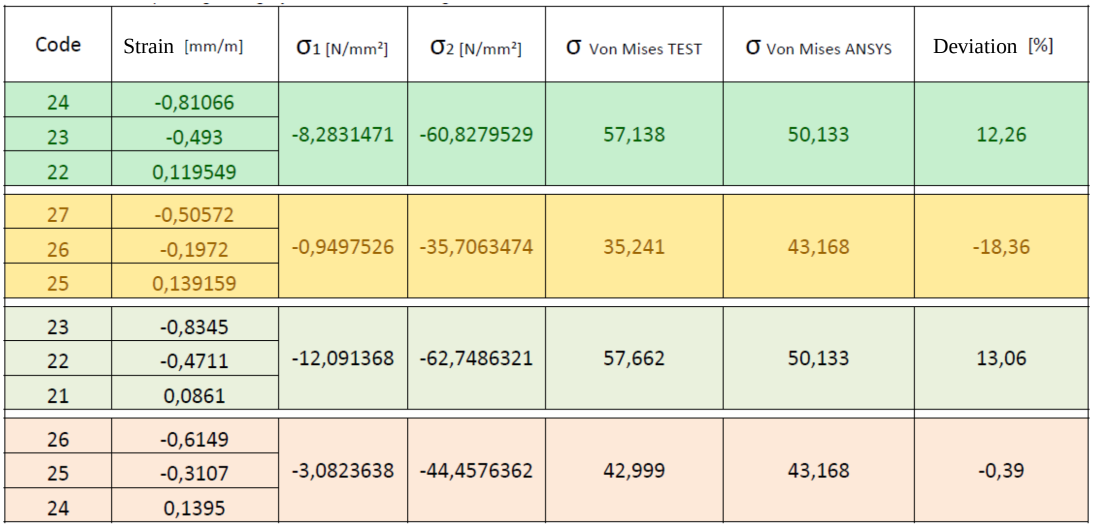


Fig. 14 Strain gauges 22 to 24 (test 1) and 21 to 23 (test 2)

Table 1: Comparison of experimental and numerical Von Mises stresses



Code	Strain [mm/m]	σ_1 [N/mm^2]	σ_2 [N/mm^2]	σ Von Mises TEST	σ Von Mises ANSYS	Deviation [%]
24	-0,81066	-8,2831471	-60,8279529	57,138	50,133	12,26
23	-0,493					
22	0,119549					
27	-0,50572	-0,9497526	-35,7063474	35,241	43,168	-18,36
26	-0,1972					
25	0,139159					
23	-0,8345	-12,091368	-62,7486321	57,662	50,133	13,06
22	-0,4711					
21	0,0861					
26	-0,6149	-3,0823638	-44,4576362	42,999	43,168	-0,39
25	-0,3107					
24	0,1395					

Differences in Von Mises stresses were acceptable: the largest deviation is 18%. It should be noticed that the Von Mises test stresses are calculated using measurements on curved surfaces. Besides that it should be noticed that in the numerical analysis material properties in the heat affected zones are supposed to be equal over the zone width, which is not the case in reality.

Conclusions

The steel design rules predict the failure behavior and failure mode of the considered N-joints well. However, they overestimate the failure load by approximately 8% for the truss configurations investigated. To improve the strength capacity in the heat effected zones near welded connections, it is suggested to replace TIG welded joints by MIG welded joints.

Acknowledgements

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