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EXPERIMENTAL INVESTIGATION OF ALUMINUM WELDED LATTICE GIRDERS

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Aluminum and its alloys are valued for their corrosion resistance, lightweight and versatile functionality within extruded profiles. However, the integration of aluminum into welded truss systems is complicated due to the formation of heat-affected zones (HAZs). In these zones, as a result of the softening effect, the reduction of load-bearing capacity is up to 50%. This complicates the design of welded joints, introducing a significant challenge to the seamless application of aluminum in such structural frameworks. The lack of specific rules for welded aluminum joints in the regulatory standard EN 1999-1-1 (EC 9) contributes to the issue. Consequently, engineers decided to use EN 1993-1-8 (EC 3), a standard not specially designed for aluminum applications, but for steel. This approach obliviously results in a conservative design process that ignores all of the advantages that aluminum alloys provide. In response to this discrepancy, our study examines the behaviour of welded joints within lattice girders, crafted from the EN AW6082 T6 alloy. This is the most widely used aluminum alloy for structures, which has yielding strength values up to those of steel S235. It is known that due to material softening during the welding process, the yield strength in the heat-affected zone (HAZ) of this alloy might drop by up to 50%. All tested lattice girders have the same chord members, which are square hollow section (SHS) 100x5 profiles. The brace members' sizes and shapes have been variated in order to perform the parametric investigation. The three trusses were built using brace members from square hollow section profiles (SHS) with widths of forty, fifty, and sixty mm; the remaining three trusses were built using braces from circular hollow section (CHS) profiles with diameters of forty, fifty, and sixty millimeters. The extensive experimental investigation combined with parametric analysis indicates complex load-bearing behavior depending on cross-section types and size. These results highlight the complex structural behaviour of aluminum lattice girders due to the peculiarity mentioned above which occurs in aluminum due to the heat input as a result of welding.

Keywords: welded aluminum joints, heat-affected zone, experimental investigation, lattice girder, square hollow section profiles, circular hollow section profiles

1 INTRODUCTION

The most straightforward way to join each component of a truss made of hollow section profiles is to weld the brace to the chord members directly. When compared to indirect welding connections made with connecting plates, direct welding provides greater structural integrity and technical safety for the entire structure. The direct transfer of force between individual elements is the reason for this.

Aluminum alloys are being used more and more in the construction industry at the same time because of their exceptional mechanical qualities and green aspects. Alloying allows aluminum alloys to achieve tensile strengths up to 500 MPa, making them competitive with steel. Because of their excellent corrosion resistance, they can be used in construction projects where harsh environmental conditions are present. Aluminum's environmental and economic sustainability is further enhanced by the simple and affordable recycling process, which makes it a green material for construction applications.

Despite this, there are no particular guidelines for calculating welded joints in trusses in EN 1999-1-1 [1], which provides design guidelines for aluminum structures. This discrepancy results from the unique properties of aluminum alloys, which necessitate taking into account factors other than those that are relevant to steel connections, such as the heat-affected zone and the consequent reduction in strength values after welding. In practice, EN 1993-1-8 [2] guidelines regulate the design of welded joints in aluminum trusses. While this code mainly deals with steel connections, it also defines common joint types that can be applied to aluminum lattice girders. Therefore, the research on directly welded joints in aluminum trusses is based on the design procedures outlined in EN 1993-1-8 [2].

The prior investigations in this area could be divided into two categories: investigations on the load-bearing capacity of lattice girder joints and HAZ research on the mechanical properties of aluminum alloys. While Đorđe Đuričić's [3] work concentrated on K-joints featuring an aluminum alloy EN AW 6082-T6 CHS profile, the majority of the second group's research has mostly dealt with steel trusses.

The load-bearing capacity of aluminum members with local transverse welds was studied by Y.F.W. Lai and D.A. Nethercot in 1993 [4]. Their findings showed that even though the HAZ has small dimensions, its softening effect on columns welded at the ends should not be ignored. The largest reduction in load-bearing capacity was seen in columns with the HAZ in the middle; these columns behaved as though the whole column was inside the HAZ. In investigating the quality of aluminum alloy welds, R. Deekhunthod's 2014 dissertation [5] noted the effects of MIG welding on the microstructure and mechanical properties of the HAZ, with a 20 mm extension from the fusion line for a 5 mm plate. It also found no significant variations in yield strength or tensile strength between welded samples from different ingots.

2 MATERIAL PROPERTIES

In the experimental phase of this research, the aluminum alloy selected was EN AW-6082 T6, a widely utilized aluminum alloy for structural applications. EN AW-6082 T6 exhibits yielding strength values within the range of steel S235. Notably, it is acknowledged that in this alloy, the yield strength in the heat-affected zone (HAZ) experiences a reduction of up to 50% due to material softening during the welding process.

A comprehensive approach was adopted to ensure the high quality of the material through the implementation of rigorous testing procedures. These procedures included advanced techniques such as digital image correlation (DIC), as shown in Figure 1.

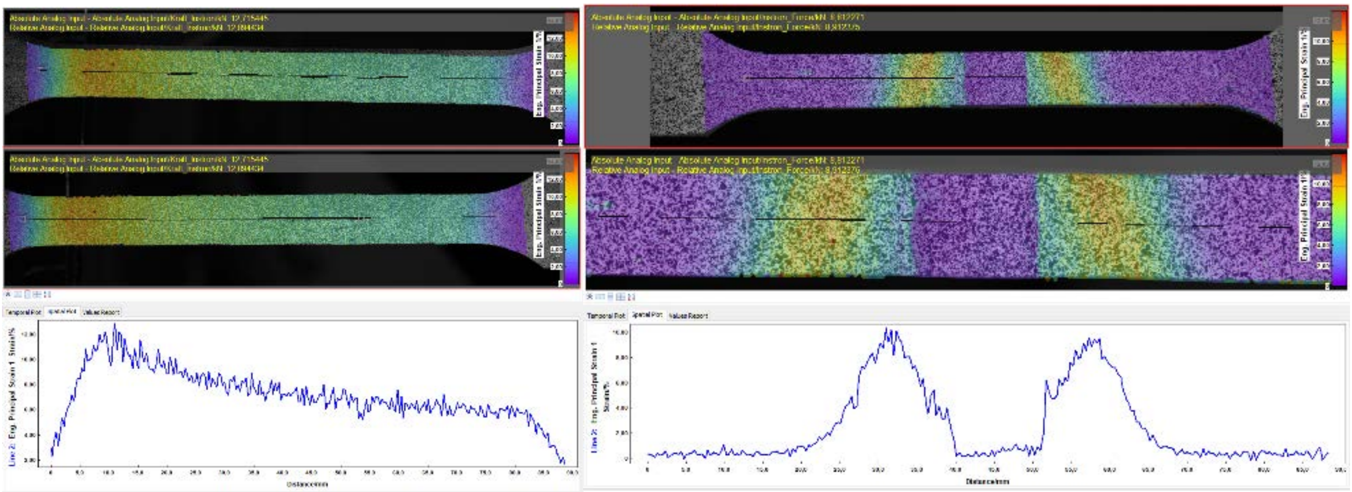


Fig. 1. Testing mechanical characteristics of EN AW 6082-T6 alloy

The outcomes of these tests, including values for yield stress (f_0), ultimate strength (f_u), and maximal elongation (A), have been presented in Table 2.

Table 2. Mechanical characteristics of base material EN AW 6082 T6

Profile	f_0 (MPa)	f_u (MPa)	A (%)
Min. reference Values EN 573-3 EN 755-2	250	290	8
CHS 40	256	297	13,6
CHS 50	270	321	8,5
CHS 60	273	320	8,6
SHS 40	251	292	10,7
SHS50	267	318	14
SHS60	254	295	12,8
SHS 100	254	295	12.8

3 GEOMETRY OF LATTICE GIRDER

The chord profile was made from SHS 100x5 and was the same in all specimens. Brace member profiles varied; they were square hollow sections SHS 40, SHS 50, SHS 60 and circular hollow sections CHS 40, CHS 50, CHS 60 (Figure 2). In total, 6 specimens have been experimentally investigated. The joints were centered without eccentricities e=0 and there was a gap whose size depended on brace member dimensions. The brace members have been joined to the chord members at the angle θi=45°. The lattice girders have been made with a constant height of 600 mm and a 3000 mm span as shown in Figure 3.

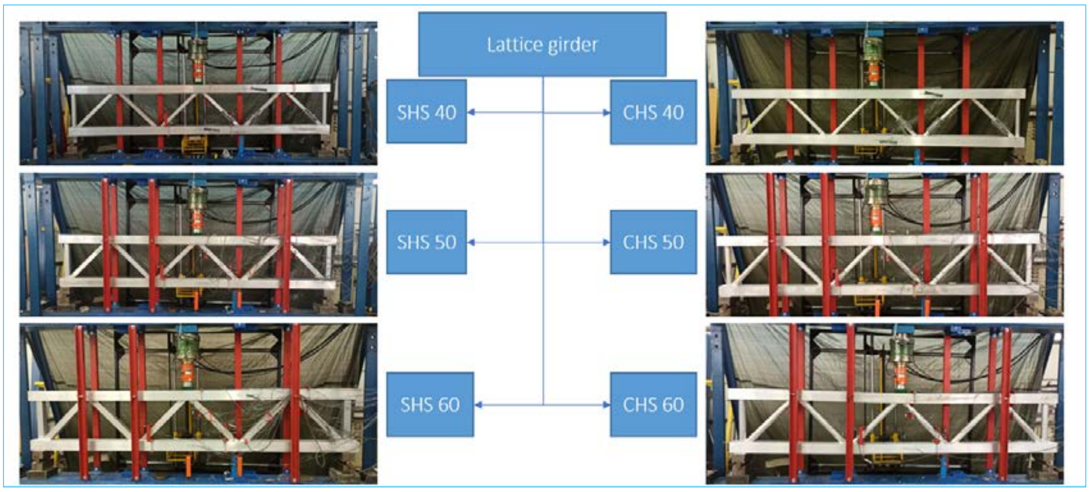


Fig. 2. Welded aluminum lattice girders- specimens

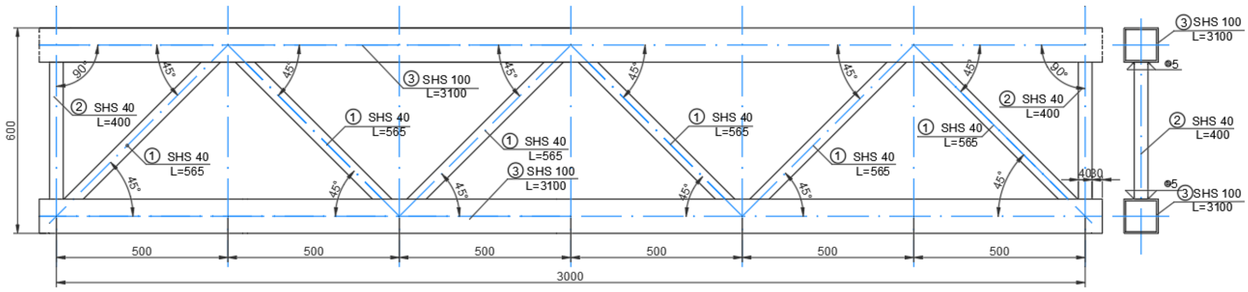


Fig. 3. Geometry of welded aluminum lattice girder

4 WELDING OF LATTICE GIRDER

Aluminum alloys from the 6xxx series can be welded by TIG or MIG welding procedure. The filler material for welding these alloys is to be chosen from the 4xxx or 5xxx series since the 6xxx series alloys have a reduction of yielding strength up to 50% due to the heat input. In EN 1999-1-1 [1] there are given two options for the filler material regarding welding of aluminum alloy EN AW-6082 T6: the first one is ER 4043 or AlSi5 which belongs to the 4xxx series and welds with this filler material are more compact but their characteristic strength is less than the same welds made with the filler material ER 5356 or AlMg5. Because of the higher characteristic strength of the welds, in this research TIG welding procedure with ER 5356 filler material rod with a diameter equal to 1.2 mm has been used, Figure 4.

Fig. 4. Welding of aluminum lattice girders

Cutting of profile tubes was done with the metal cutting band saw with cooling emulsion so that there is no heat input which could affect the mechanical properties of the material. Cleaning has been performed before welding and again after every weld layer to reduce the presence of Al2O3. The cleaning process has been done mechanically using a stainless-steel wire brush. After the mechanical surface cleaning, welding was carried out.

5 DISPOSITION OF THE EXPERIMENTAL INVESTIGATION

The designations for the trusses are determined by the brace member cross-section profile; square profiles are assigned SHS40, SHS50, and SHS60, while circular hollow section profiles are assigned CHS40, CHS50, and CHS 60. The ratio of the brace member width to the chord member width is represented by the β coefficient, which ranges from 0.4 to 0.6. Every joint is made in compliance with EN 1993-1-8 specifications. K-joints in compressed chord members are labeled as KC, with positions displayed in Figure 5, and those in tensioned chord members are labeled as KTL and KTR.

Fig. 5. Welded aluminum joints positioned inside lattice girder

As shown in Figure 6, the truss is loaded with a concentrated force in the middle of the span (D), supported at points A and B, and installed in a testing frame. local N joint deformation above supports is prevented. In the event of buckling, bolts in a point connected with U steel profiles lateral secure the compressed chord member of the lattice girder every 500 mm. The applied force is measured through force transducer (I) above which is placed hydraulic press (D). Displacement transducers attached on chord members are used to measure the local deflection of their faces. Local K-joint deflections were measured by displacement transducers attached to chord members (III, IV, V), whereas the global deflection of the truss was measured by displacement transducers attached to the steel frame (VI, VII). While the local displacement of the X joint was measured by the displacement transducer II.

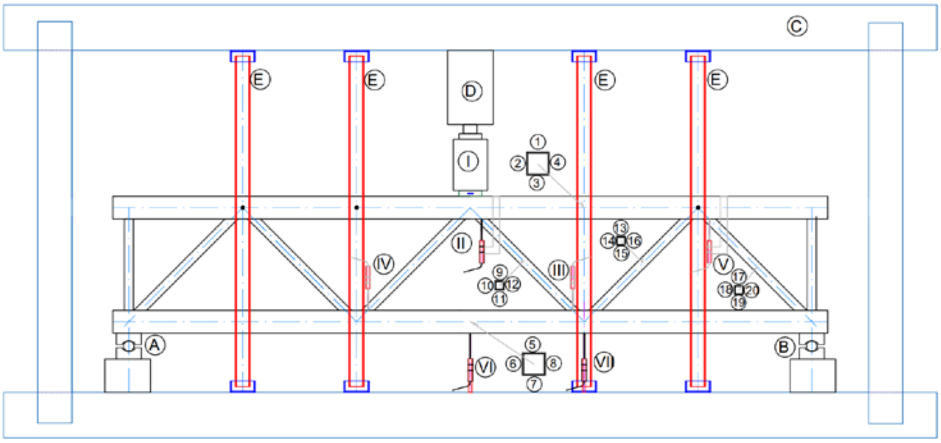


Fig. 6. Schematic disposition of testing aluminum lattice girder

Axial forces inside members were indirectly calculated based on the relationship between axial force-normal stress, and strain. Strains are measured using TML strain gauges (FLAB-5-23-5LJCT-F) located in the middle of the span of members, Loading begins with an initial force of 0.5 kN, incrementally increasing until K-joint plastification is recorded and global collapse of structure is experienced, revealing joint deformations without further load growth.

6 FAILURE CRITERIA

Upon analyzing how loads are transferred within the joint, potential fracture locations can be pinpointed. The resulting fracture forms are determined by considering the stiffness distribution and material characteristics of the specific location. The joint's load-bearing capacity is determined by the minimal load at which a fracture occurs in one of these possible locations. This research focuses on examining a particular kind of failure known as chord face plastification, which appears as the main failure mode when the brace-to-chord member ratio is less than 0.85, but also investigates the load-bearing capacity of the joint thill the structure collapses taking into consideration other types of possible failures which are presented later in the paper. Load-bearing capacity can be assessed by a variety of criteria. On the other hand, the limit state of deformations is the most widely applied criterion for assessing the load-bearing capacity of welded joints in case of a chord face plastification. The limit state of local deflection is defined based on local deflections of the chord member face close to the welded brace member, in the vicinity of the weld. As Lu et al. (1994) specified, this limit is determined by the width (b_0) of the chord member. These criteria serve as guidelines to ensure the structural integrity and performance of joints by restricting deformations within acceptable limits. For square (SHS) and rectangular (RHS) hollow section profiles, the majority of regulations specify a maximum local deflection of 3% b_0. Furthermore, for RHS and SHS profiles at the serviceability limit state, an arbitration value of 1% b_0 has been adopted [3], Figure 7. In the case of CHS joints, instead of the width of the chord, the diameter d0 of the chord is used. Therefore, the serviceability limit state is defined with 1% d_0, while the ultimate limit state is defined with 1% d_0.

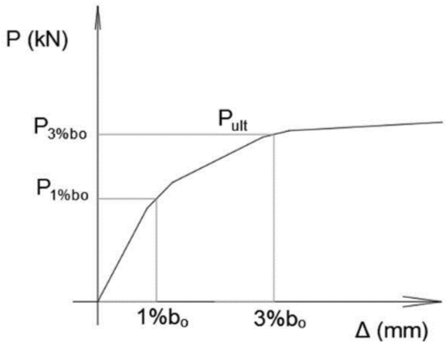


Fig. 7. Deformation limit criteria

7 RESULTS

Based on experimental results, for lattice girders with coefficient β with values 0.4 and 0.5, EN 1993 part 1-8 [3] describes well the critical failure mode, while for the lattice girders where β=0.6, the upper limit for critical chord face plastification failure should be further examined and reviewed in case of welded hollow section joints.

Special attention should be paid to weld inspection of the joints of welded aluminum lattice girders, especially in case of circular hollow section profiles as part of lattice girder as for the CHS 60 lattice girder crack inside weld was critical failure mode, which doesn't comply with theoretical assumptions.

Local joint failure in some cases doesn't lead to immediate global failure of lattice girder especially for the lower values of coefficient β, in experiment for value 0.4.

Table 3. Failure modes for investigated lattice girders

LATTICE GIRDER	CRITICAL FAILURE MODE	II FAILURE MODE	III FAILURE MODE	IV FAILURE MODE
SHS 40	X JOINT CHORD FACE PLASTIFICATION	X JOINT SIDE WALL CHORD PROFILE BUCKLING	K JOINT CHORD FACE PLASTIFICATION	
SHS 50	X JOINT CHORD FACE PLASTIFICATION	X JOINT SIDE WALL CHORD PROFILE BUCKLING	K JOINT CHORD FACE PLASTIFICATION	WELD FAILURE IN TENSIONED BRACE
SHS 60	X JOINT SIDE WALL CHORD PROFILE BUCKLING	X JOINT CHORD FACE PLASTIFICATION		
CHS 40	X JOINT CHORD FACE PLASTIFICATION	K JOINT CHORD FACE PLASTIFICATION	WELD FAILURE IN TENSIONED BRACE	
CHS 50	X JOINT CHORD FACE PLASTIFICATION	X JOINT SIDE WALL CHORD PROFILE BUCKLING	K JOINT CHORD FACE PLASTIFICATION	WELD FAILURE IN TENSIONED BRACE
CHS 60	WELD FAILURE IN TENSIONED BRACE			

Lattice girders with lower values of coefficient β have shown higher ductility capacity or deformation capability compared to ones with higher values, as shown in the Figure 8. Regarding the shape of brace members for the same values of coefficient β, it could not be stated what is the more favorable options regarding global ductility as CHS lattice girders are more prone to weld failure and the plastification of the joints didn't occur in some of the cases.

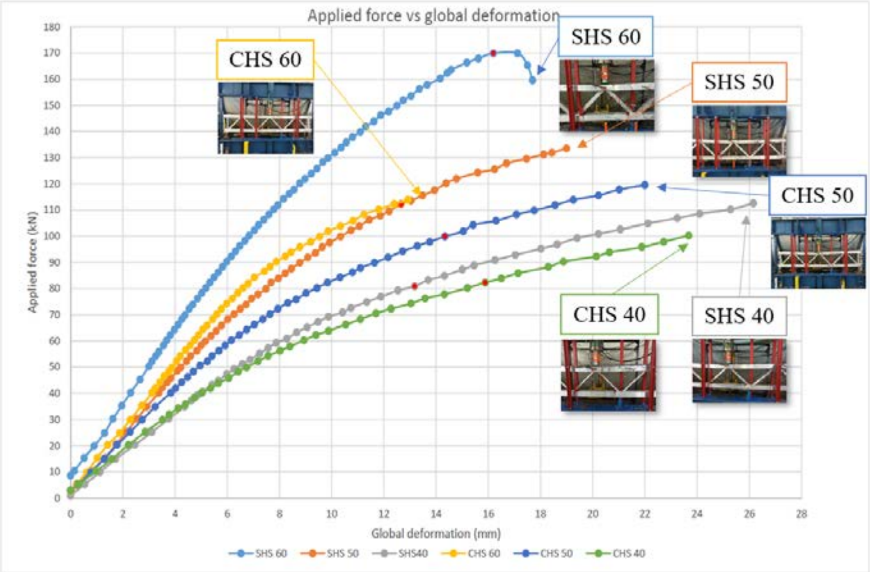
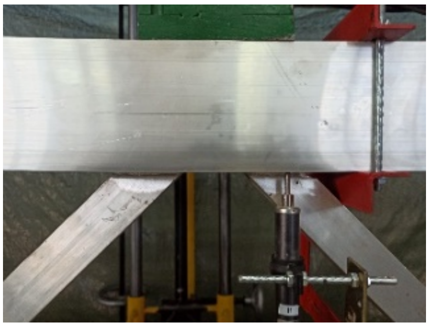
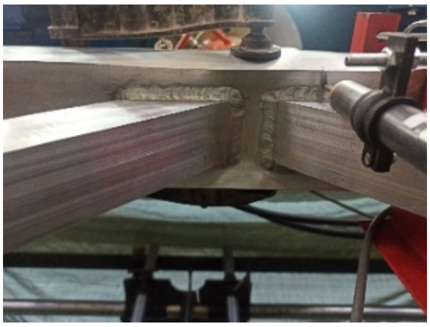
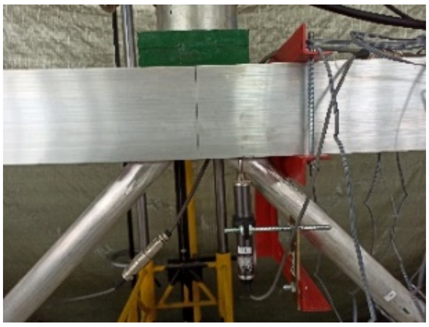
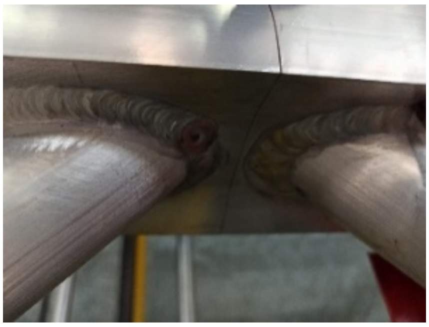


Fig. 8. Applied force- global deformation curves

Failure criteria previously defined based on deformation limit for experimental investigation of welded steel hollow section joints could be used in the case of welded aluminum joints. As for the welded steel joints, the same rule apply to aluminum joints, higher values of β imply higher values of critical force in the case of chord face plastification, as shown in case of X joints in Table 4.

Table 4. X joint cord face plastification

X JOINT FACE PLASTIFICATION		
		
SHS 40	SHS 50	SHS 60
Fcr= 43,306 kN	Fcr= 63,597 kN	Fcr= 99,487 kN
		N/A
CHS 40	CHS 50	CHS 60
Fcr= 44,545	Fcr= 56,467	N/A

8 CONCLUSIONS

In summary, the research investigates the welding of aluminum lattice girders, emphasizing the advantages of direct welding for structural integrity. The use of EN AW-6082 T6 alloy in construction is highlighted for its mechanical properties and eco-friendly characteristics. However, the absence of specific guidelines for aluminum structures in existing standards necessitates reliance on principles designed for steel connections. The experimental investigation reveals critical failure modes, emphasizing the importance of weld inspection and providing insights into the deformation capabilities of lattice girders. Overall, the study offers practical considerations for the application of aluminum in construction, bridging gaps in industry standards. Further experiments are planned with an aim to derive an aluminum-specific design procedure.

9 LITERATURE

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