Low-temperature fatigue life properties of Aluminum butt weldments by the means of the local strain energy density approach

[1]Luigi Mario Viespoli, [2]Andrea Leonardi, [2]Filippo Cianetti, [3]Bård Nyhus, [3]Antonio Alvaro, [1]Filippo Berto

[1]Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology (NTNU), Norway

[2]Dipartimento di Ingegneria Industriale, University of Perugia, Italy

[3]Department of Materials and Nanotechnology, SINTEF Industry, Norway

ABSTRACT: The paper investigates the use of the strain energy density evaluated on a finite control volume as a mean to the fatigue life prediction for double V-groove but joints. The specimens are manufactured by MAG welding of AA6082-T4, fatigue tested in as weld condition by loading orthogonally to the welding direction with a load ratio R=0 and R=0.5. The aim of the paper is to apply the SED method to butt-welded joints and verify its soundness for this class of joints, comparing the test result with numerical solutions. A comparison of the fatigue results using and SED method both Nominal stress approach is reported. A numerical model has been realized in plane strain hypothesis from an ideal non-distorted geometry and the stresses corrected according to the average specimen measures. The results show an agreement of the fatigue resistance with the Nominal Stress S-N curves and the SED curve for aluminum welded joints both at room temperature (+25 °C) and at arctic temperature (-60 °C).

Fatigue testing

The fatigue testing has been carried on two series of double V-groove butt-welded joints realized by semi-automatic MIG process. The material has been received in the form of 180x20x2000 mm and 150x5x2000 mm plates of AA6082-T4 aluminum alloy. The results of the welding process can be observed in Figure 1. In the case of the 5 mm thick joints, partial recrystallization of the base material can be observed and porosity is detected, but not in critical levels. For the 20 mm thick joints the level of porosity is similarly non critical but the presence of lack of side wall fusion areas is not allowed for quality level B and C of NS-EN ISO 10042:2005.

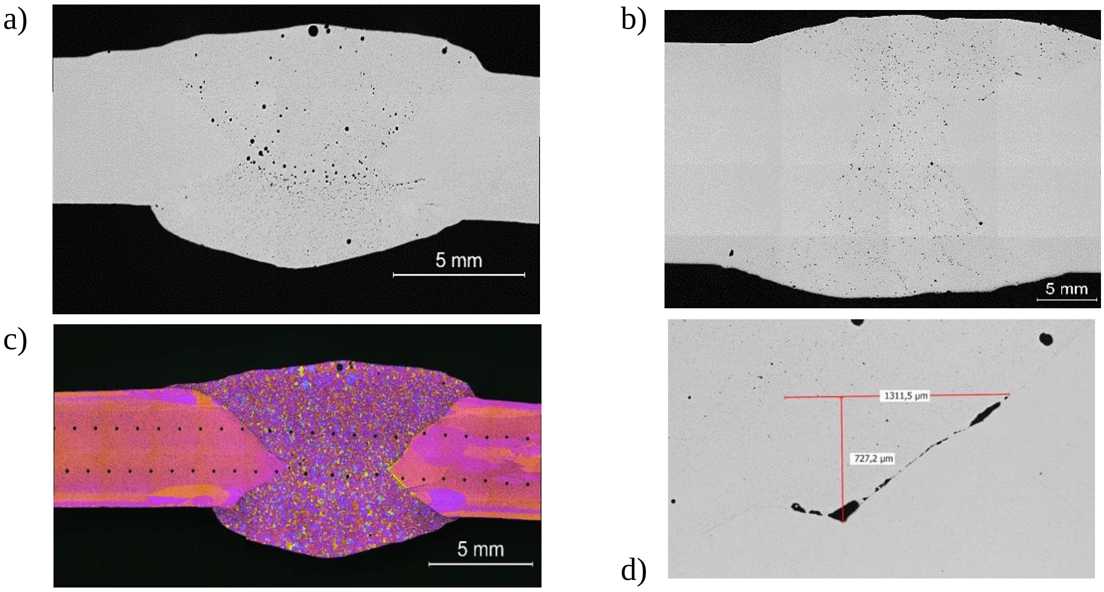

Figure 1. Defects such as porosity and lack of side-wall fusion are present in the weldments.

The plates have been clamped before the execution of the welding to limit the angular misalignment of the plates. Nevertheless, the joints result to have an angular misalignment which will affect the real stress field acting on the joint due to the rigid clamping of the fatigue testing machine. The equivalent stress acting can be computed from the distortion and stiffness of the joint according to the corrective factor suggested by the IIW document by Hobbacher [1]. The fatigue testing has been performed in atmosphere with a sinusoidal load cycle by a MTS servo-hydraulic machined with a 100 kN load cell and testing frequency f=10 Hz. The results of different conditions are presented: testing at load ratio R=0 at +25 and -60 °C for the specimens of both thicknesses [2] plus testing the 20 mm thick specimens at room temperature with a load ratio R=0.5. Hobbacher suggests S-N curves for the case of R=0.5 and no correction for smaller R in case of high residual stresses, thick walled weldments and complicated geometries. As observed in fig. 2.a, the difference between the fatigue curve for the two load ratios is negligible, in accordance with what proposed. In general, all the samples respect the fatigue class reported by Hobbacher, with the thinner specimens outperforming the fatigue strength of the thicker ones in terms of corrected nominal stress. Also, the samples testing at arctic temperature have shown a good performance, indicating the feasibility of the material for the use in structures subjected to cyclic loads at low temperature. The results are also in agreement with the SED curve for aluminum welded joints available in the literature [3]. The use of the SED is indicated for the negligible mesh sensitivity correlated to the ability to consider the effects of the local stress strain distribution with critical value independent from notch opening angle [4-8].

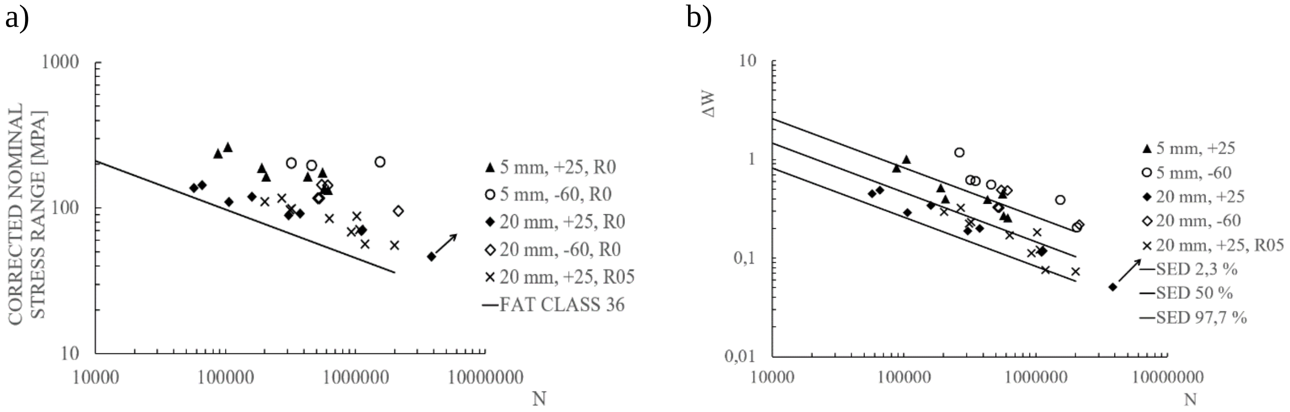

Figure 2. Fatigue testing results in terms of corrected nominal stress and average strain energy density.

In fig. 3 relevant examples of final fractures can be observed. Captures 3.a and 3.c report fractures for 5 mm thick specimens tested at ΔS=100 MPa at room and arctic temperature respectively showing identical failure mode. In the case of the 20 mm joints, crack propagation is mostly orthogonal to the loading direction for the lower loads 3.b while it follows the side wall for the higher loads 3.d.

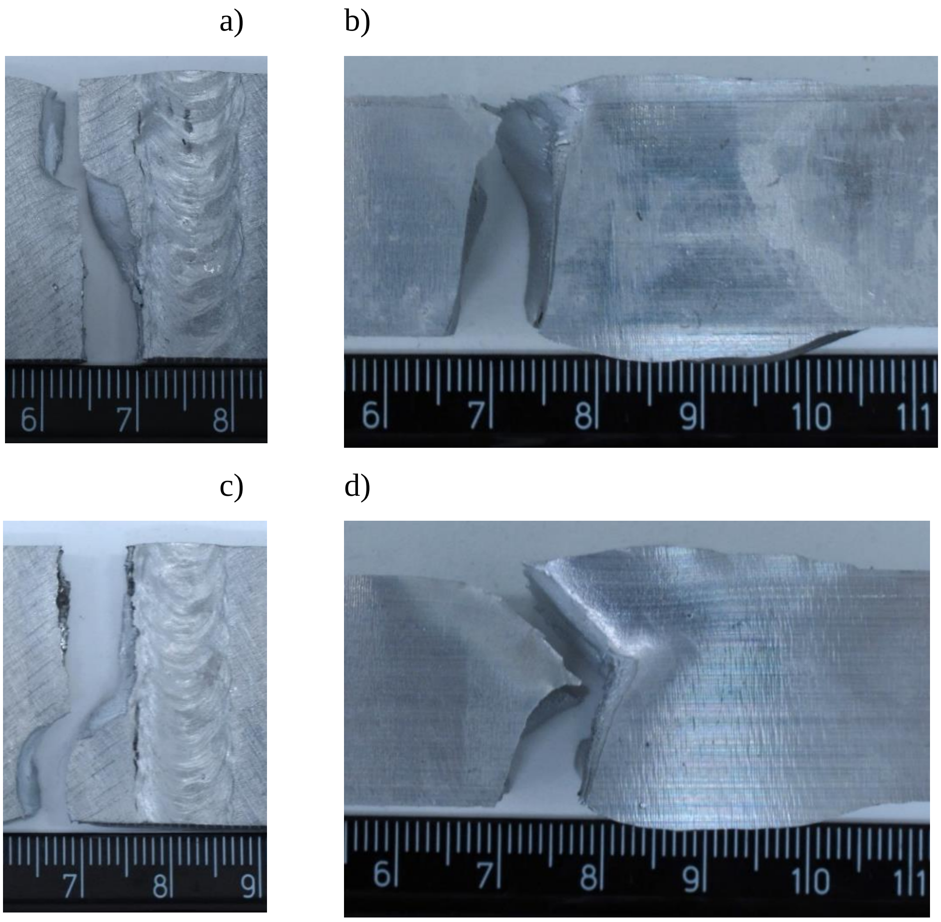

Figure 3. Relevant examples of fatigue fractures at different temperature and load level.

Conclusions

In this work, the results of the fatigue testing on two series of AA6082-T4 double V-groove butt welded joints are reported. The joints, realized from 20 mm and 5 mm thick plates by semi-automatic MAG welding, have been fatigue tested at room (+25 °C) and arctic temperature (-60 °C). The main conclusions are:

- After correcting the stress for the distortion of the joints, the thinner specimens show a better fatigue resistance;
- The reduction of the testing temperature causes an increased fatigue resistance for both the thicknesses tested;
- The different temperatures do not cause a difference in the fracture modality;
- The failures originate from local stress hot spots at the weld toe caused by the geometry of the weld bead.

The authors wish to thank the Research Council of Norway for funding through the Petromaks 2 Programme, Contract No.228513/E30. The financial support from ENI, Statoil, Lundin, Total, Scana Steel Stavanger, JFE Steel Corporation, Posco, Kobe Steel, SSAB, Bredero Shaw, Borealis, Trelleborg, Nexans, Aker Solutions, Marine Aluminum, FMC Kongsberg Subsea, Hydro and Sapa are also acknowledged.

References

[1] Hobbacher A. Reccomandations for fatigue design of welded joints and components. IIW document IIW-1823-07.

[2] Viespoli L M, Alvaro A, Nyhus B, Berto F. Fatigue investigation of complex weldments by the means of the local strain energy density approach. MATEC Web Conf. 2018; 165: 22003.

[3] Livieri P, Lazzarin P. Fatigue strength of steel and aluminium welded joints based on generalised stress intensity factors and local strain energy values. Int J Fract. 2005; 133: 247-276.

[4] Lazzarin P, Tovo R. A notch intensity factor approach to the stress analysis of welds. Fatigue & Fracture of Engineering Materials & Structures. 1998; 21: 1089-1103.

[4] Lazzarin P, Zambardi R. A finite-volume-energy based approach to predict the static and fatigue behavior of components with sharp V-shaped notches. International Journal of Fracture. 2001; 112: 275–298.

[5] Williams M L. Stress singularities resulting from various boundary conditions in angular corners of plates in tension. J Appl Mech. 1952; 19: 526–528.

[6] Berto F, Lazzarin P. A review of the volume-based strain energy density approach applied to V-notches and welded structures. Theoretical and Applied Fracture Mechanics. 2009; 52(3): 183-194.

[7] Berto F, Lazzarin P. Recent developments in brittle and quasi-brittle failure assessment of engineering materials by means of local approaches. Materials Science and Engineering: R: Reports. 2014; 75: 1-48.

[8] Viespoli L M, Somà A, Berto F. Fatigue life assessment for a welded detail: advantages of a local energetic approach and experimental validation. Frattura ed Integrità Strutturale. 2018; 45: 121-134.