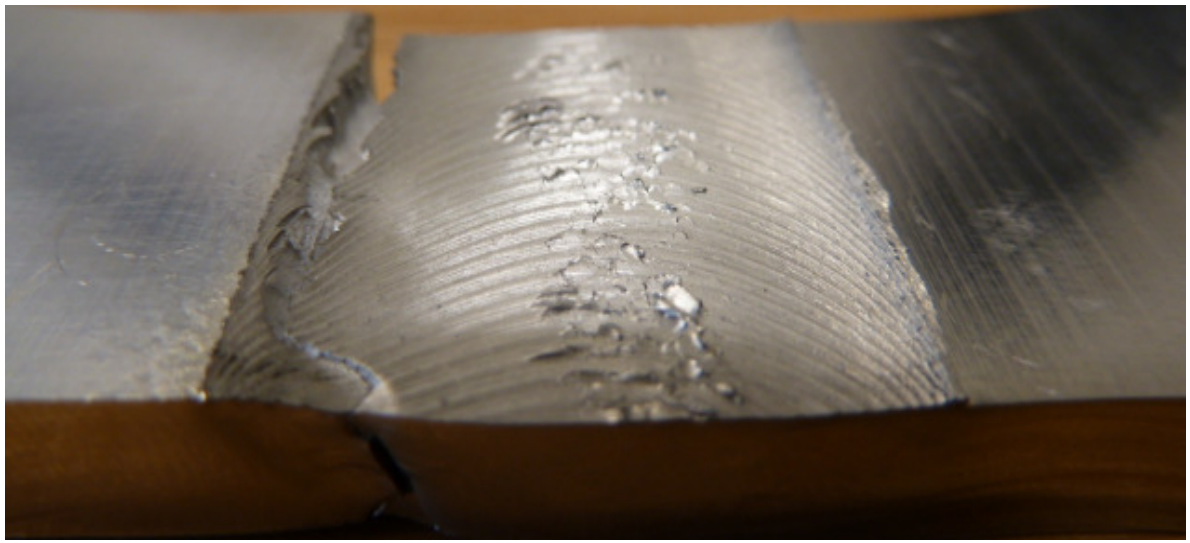
Fatigue and tensile properties of friction stir welds in AA6061-T6 and AA6082-T6 from production trials

Jesus Mendoza
Sapa Technology
Finspong, Sweden.



1. Introduction

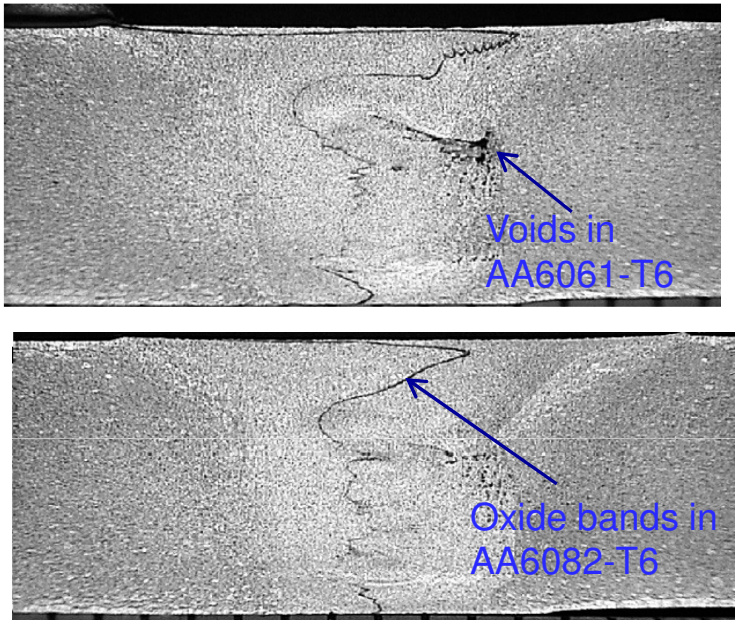
- In a previous investigation at Sapa Technology [1,2], fatigue tests were performed in friction stir welded butt joints in AA6061-T6 and in AA6082-T6.

- FS welds were made using an in-house 5-axis TOS milling machine at Sapa Technology → therefore called “laboratory welds”.

- Two types of welds were obtained: flaw-free welds and welds containing flaws (by deliberately choosing welding parameters outside the common process window).

- Fatigue strengths of flaw-free FS welds in both materials were very good.

- For the present project, friction stir butt welds in AA6061-T6 and AA6082-T6 were made in the Sapa long-length facility in Finspong → therefore called “production welds” in this presentation.



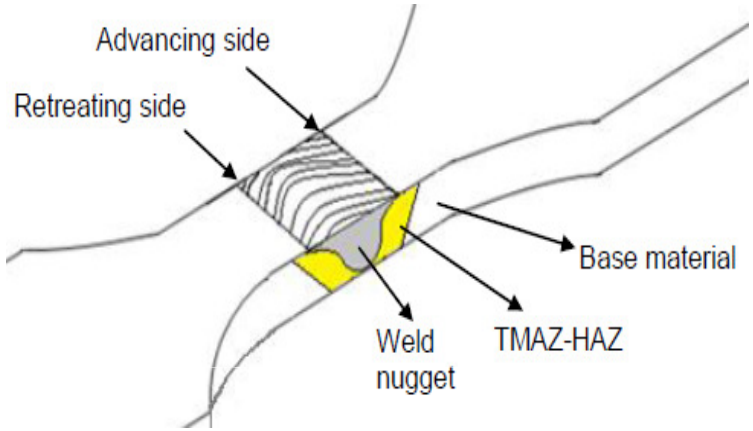
[1] S. Kahl. “The influence of small voids on the fatigue strength of friction stir welds in the aluminium alloy AA6061-T6”. Heron, Vol 55 (2010).
[2] S. Kahl. “Fatigue strength of friction stir welds in aluminium alloy AA6082-T6”. 8th International TWI Friction Stir Welding Symposium (2010).

2. Experimental procedure

Mechanical testing

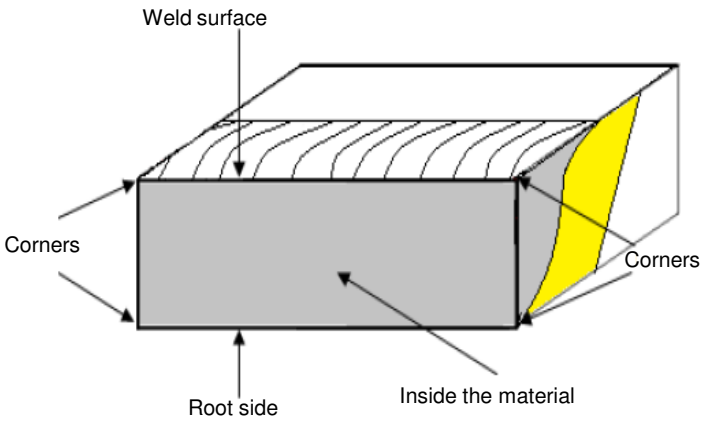
- Tensile tests: according to ISO 6892-1:2009
- Bending tests: free-bend with root under tension
- Micro hardness tests: Vickers at 200 g load
- Axial stress-controlled fatigue tests.

100 Hz testing frequency.
Load ratio ($R = S_{min}/S_{max}$) equal to 0.5
Tests stopped after 40 million cycles.
Test temperature = 20 ± 2 ℃.



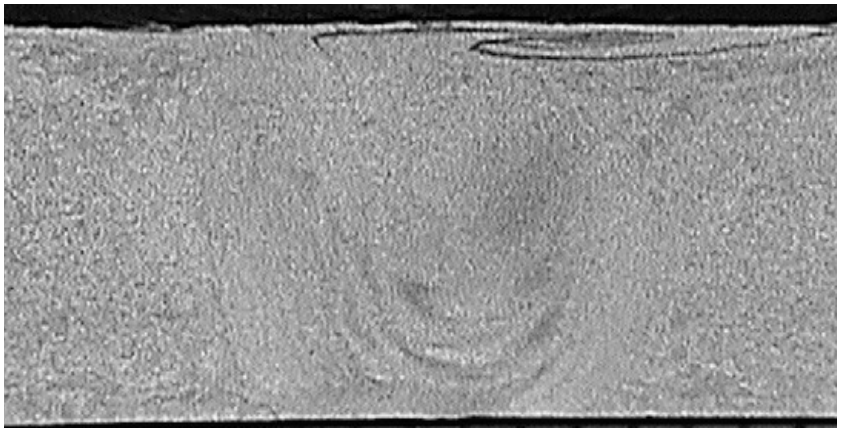
Optical microscope inspection

- Metallographic investigation of small pieces in the vicinity of the welds.
- Identification of the fatigue crack initiation sites in optical stereo microscope.

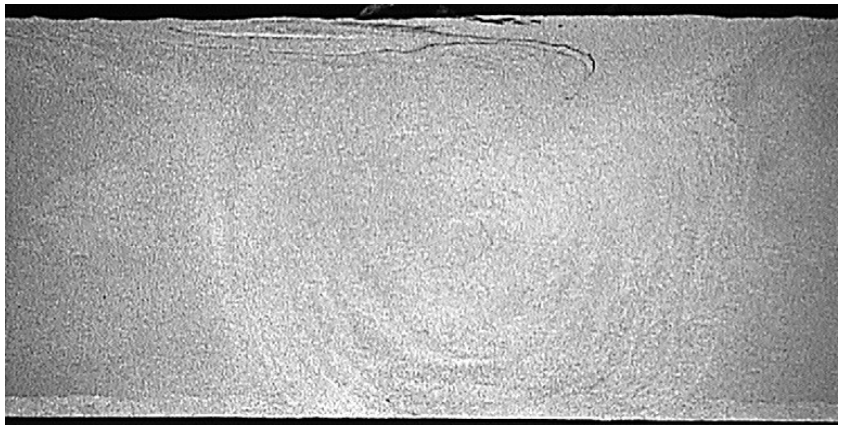


3.1 Metallographic inspection of the welds

AA6061-T6



AA6082-T6



Metallographic samples confirmed the absence of cavities or incomplete penetration of the production welds

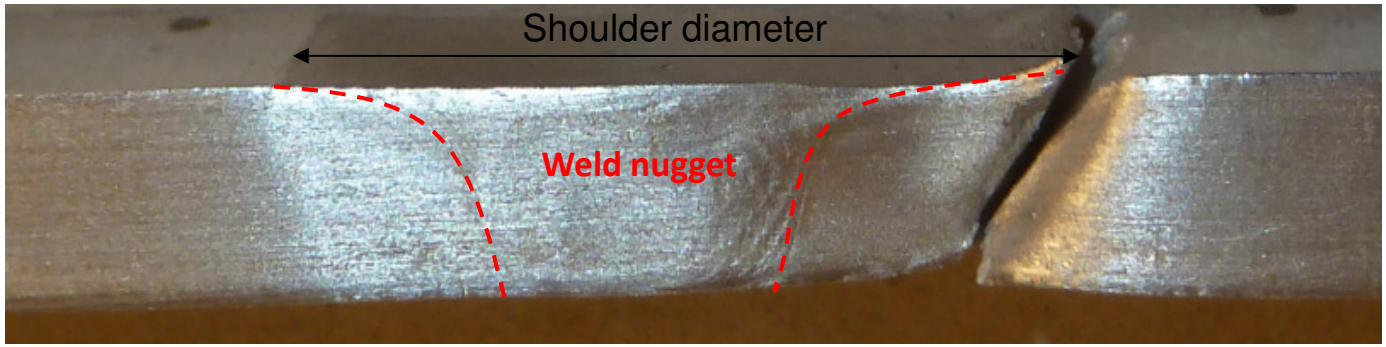
3. Results

3.2 Tensile tests

AA6061-T6			
Specimen	***$R_{p0.2}$ (MPa)***	***R_m (MPa)***	***A_{50mm} (%)***
FS welds	144 ± 3	226 ± 1	8.6 ± 0.8
Base material	265 ± 0	287 ± 0	11.7 ± 0.5
Joint efficiency	-	*79 ± 0.4%*	-
AA6082-T6			
FS welds	173 ± 4	269 ± 3	8.2 ± 0.5
Base material	300 ± 2	348 ± 0	17.4 ± 0.1
Joint efficiency	-	*77 ± 0.9%*	-

Mean value ± 2 standard deviations

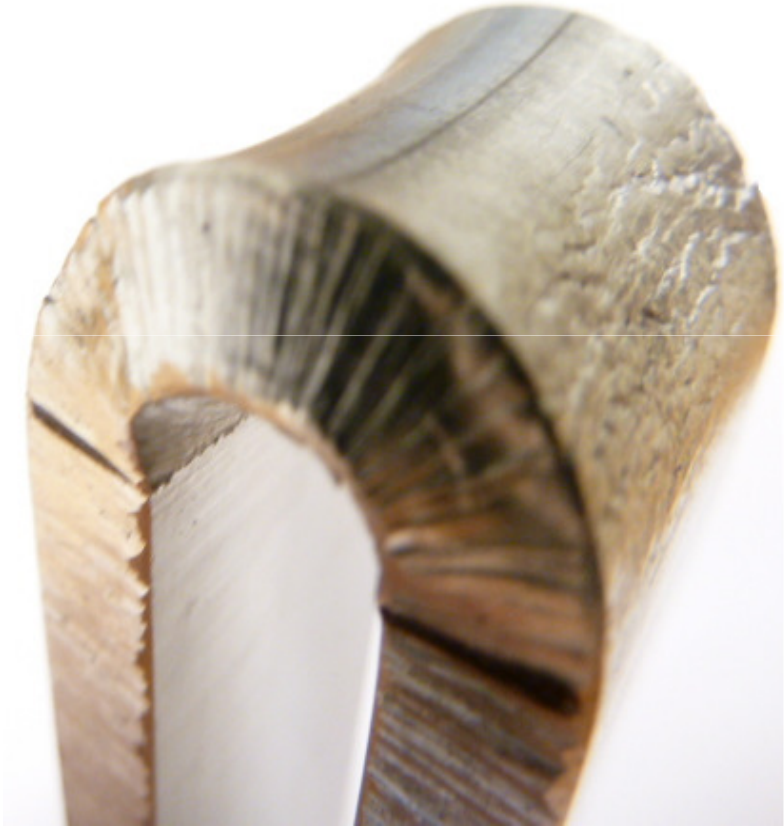
In tensile test, all fractures occurred in the TMAZ-HAZ



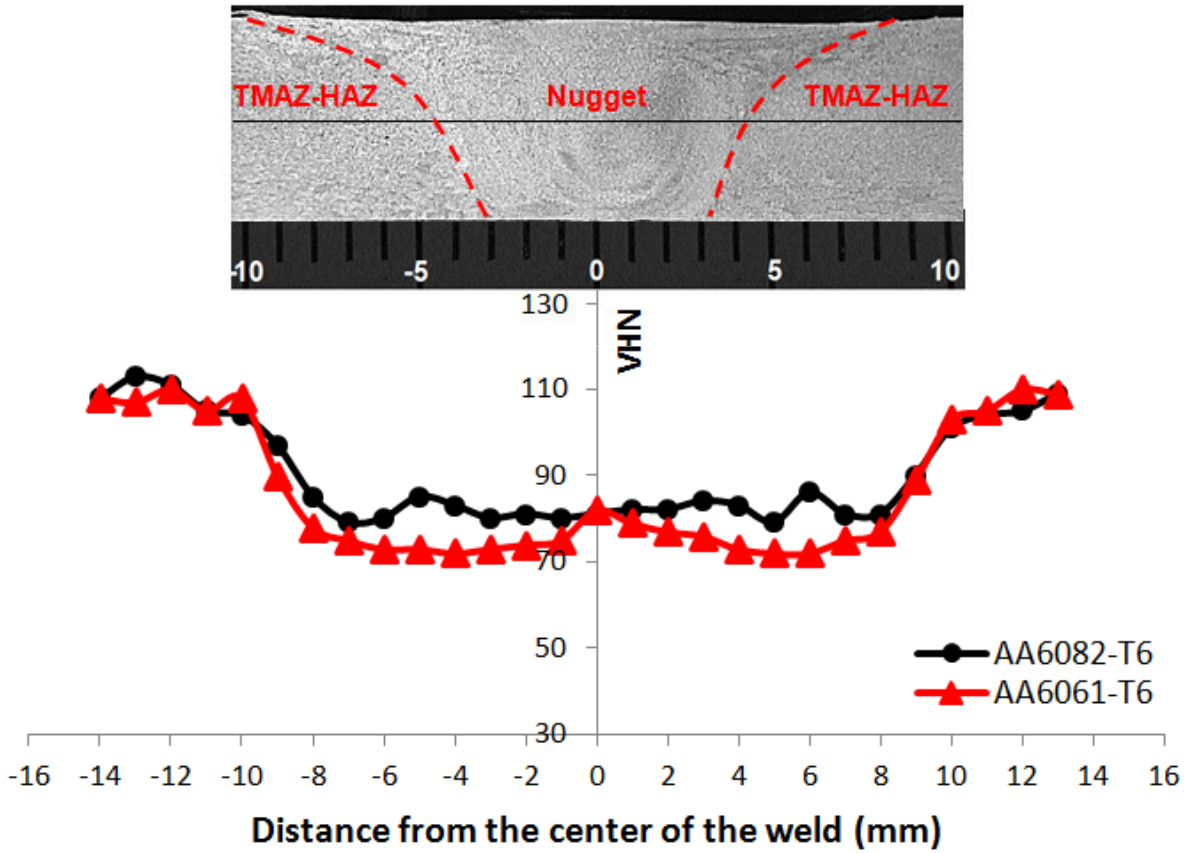
3.3 Bending tests

Eight specimens of FS welds in AA6061-T6 and four in AA6082-T6.

No incomplete penetration was detected!



3.4 Micro hardness tests



- The hardness profiles were symmetric with respect to the center of the weld.

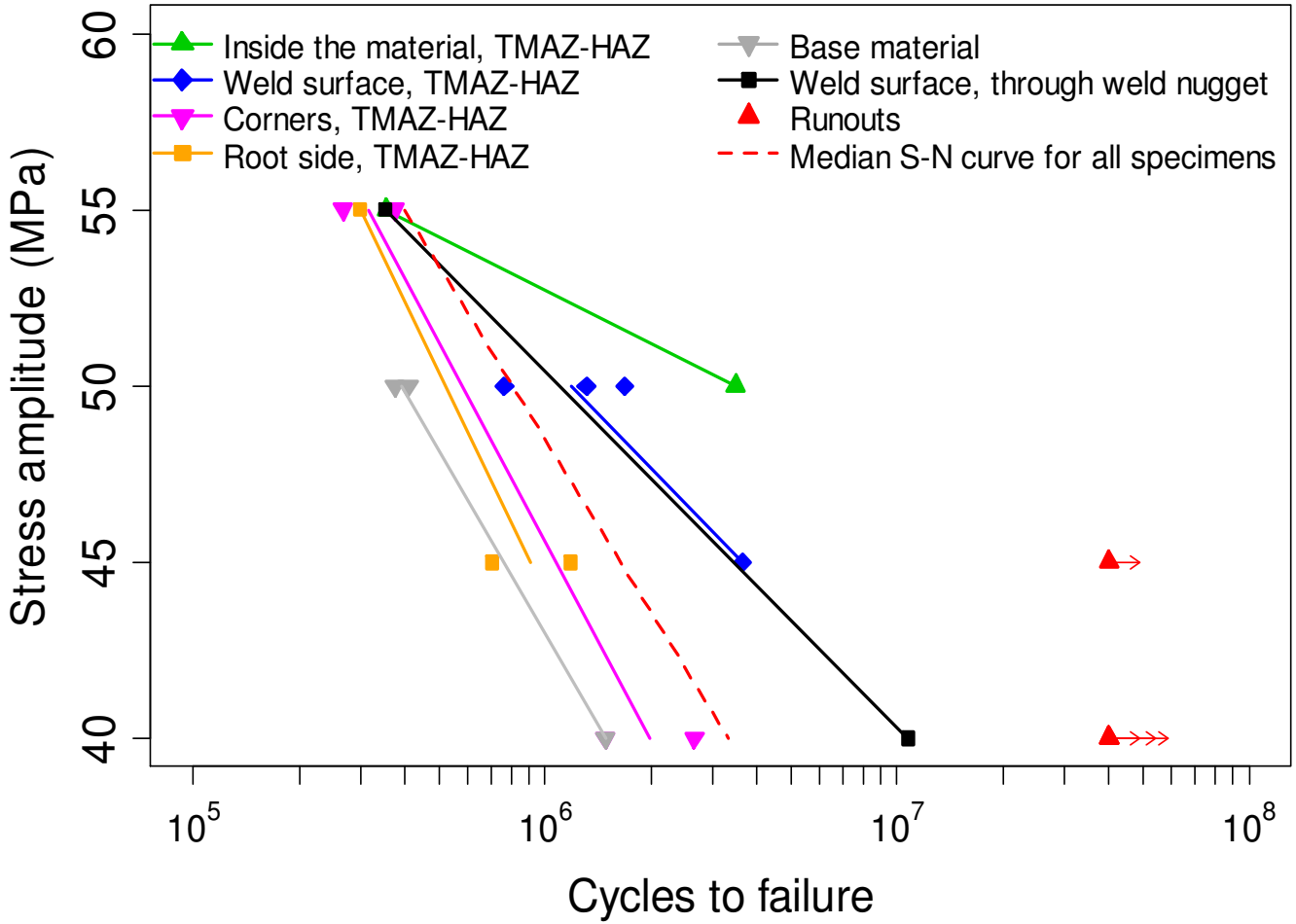
- The hardness of the weld nugget was lower than in the TMAZ-HAZ for both materials.

- The micro hardness in the weld nugget of the FS weld in AA6082-T6 was slightly higher than of the FS weld in AA6061-T6 (8-10 VHN)

3.5 Fatigue tests: Stress-life curves by crack initiation sites

FS welds in AA6061-T6

A correlation was found between fatigue crack initiation sites and the fatigue life

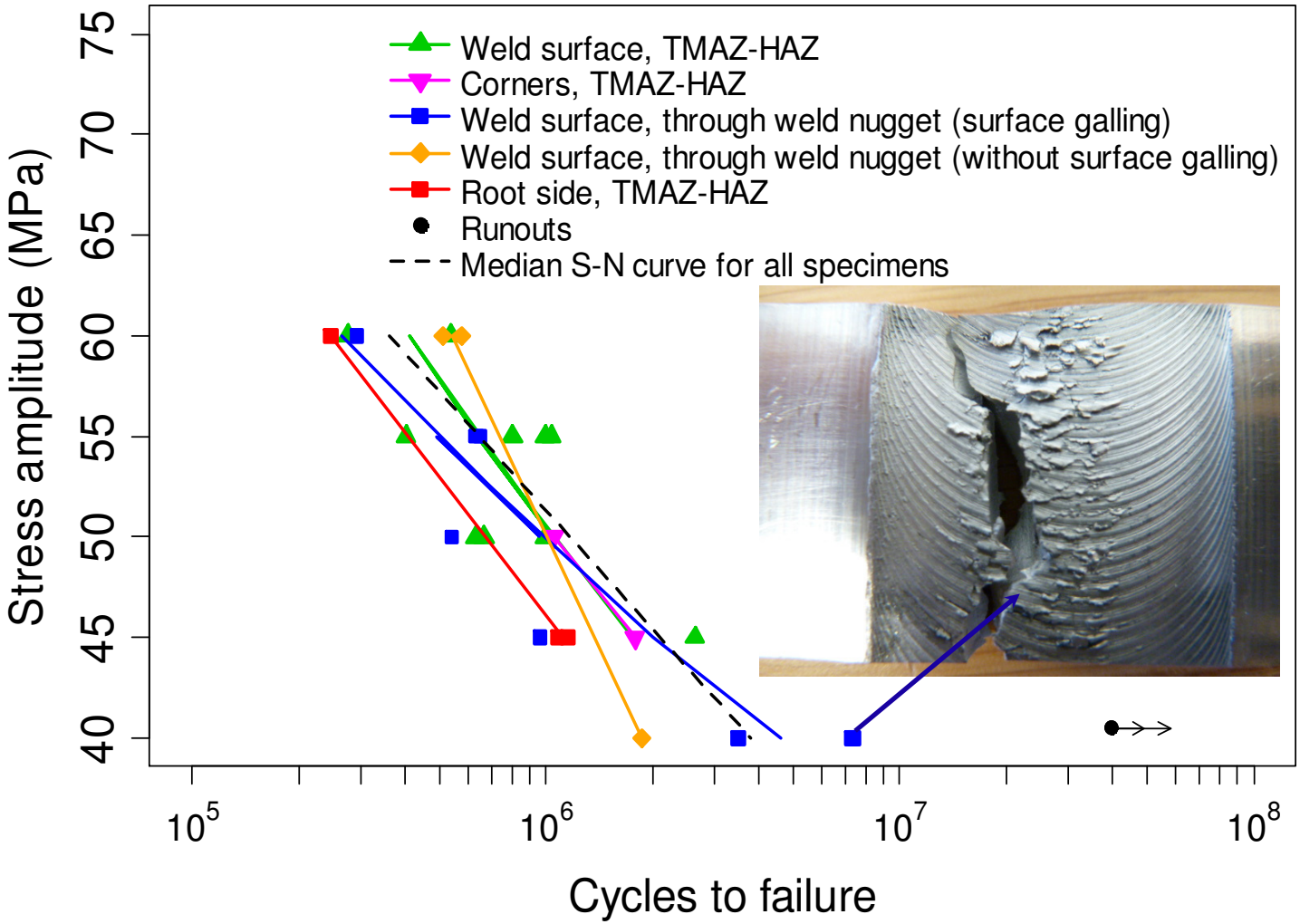


3.5 Fatigue: Stress-life curves by crack initiation sites

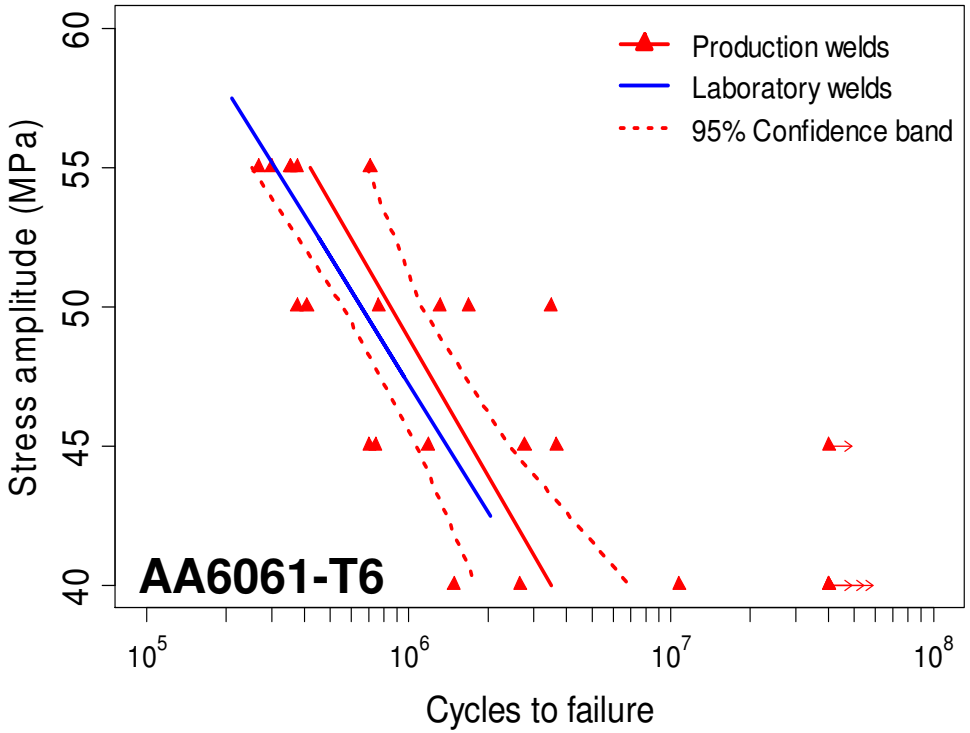
FS welds in AA6082-T6

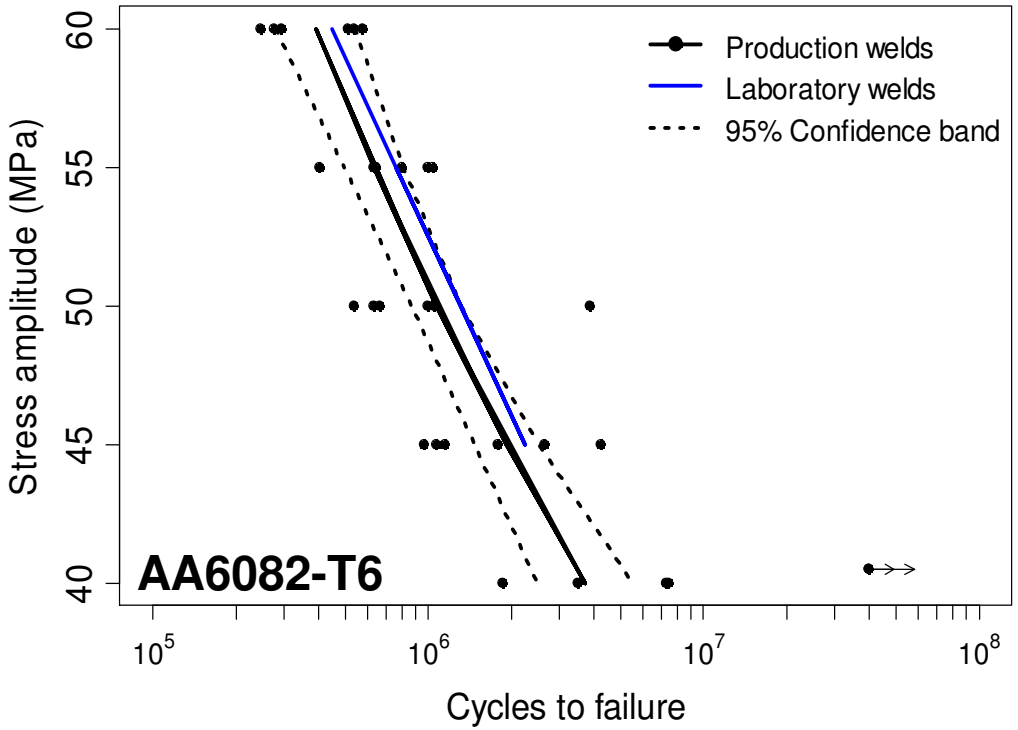
- No correlation was found between the crack initiation sites and fatigue life.

- The presence of surface galling did not reduce the average fatigue life of the production welds.



3.6 Fatigue: Production welds vs. laboratory welds



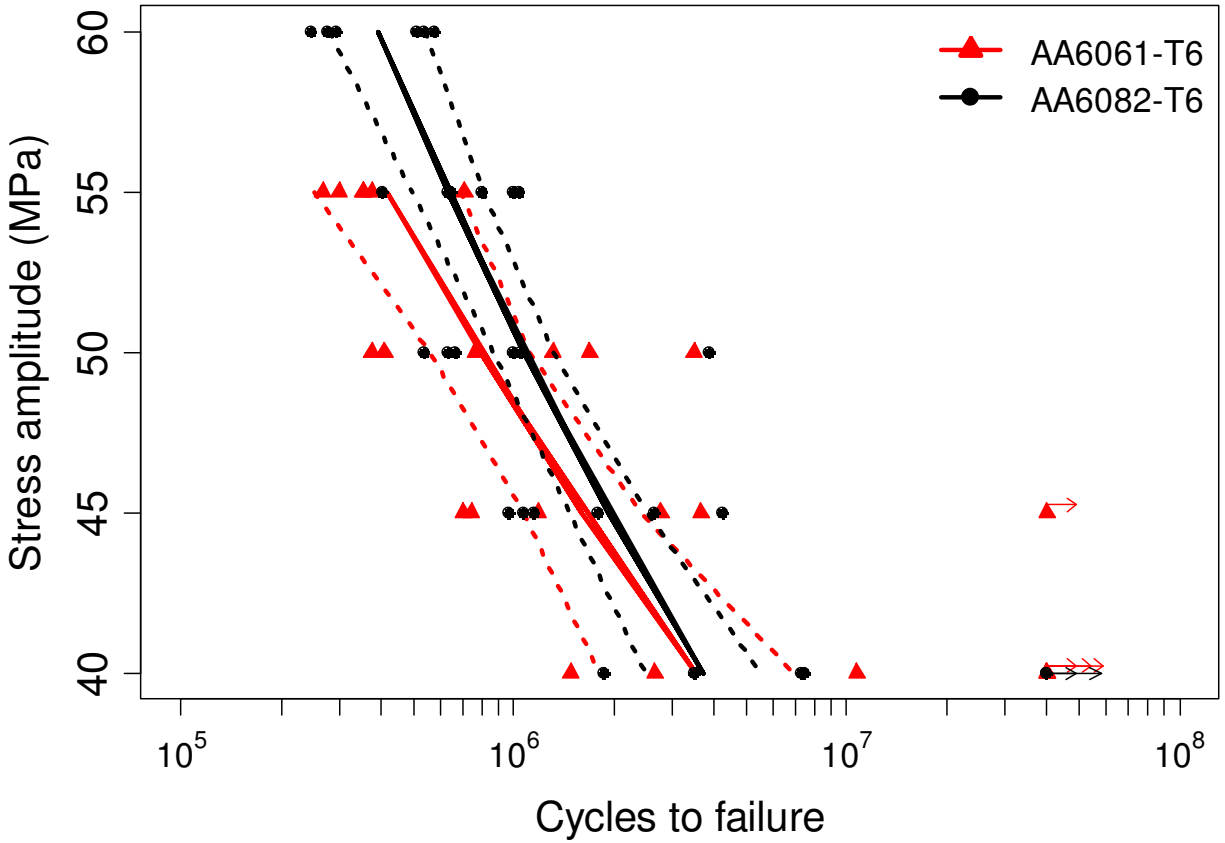


No statistically significant difference between the fatigue lives of the production welds and the laboratory welds despite of substantial differences in tools and welding parameters.

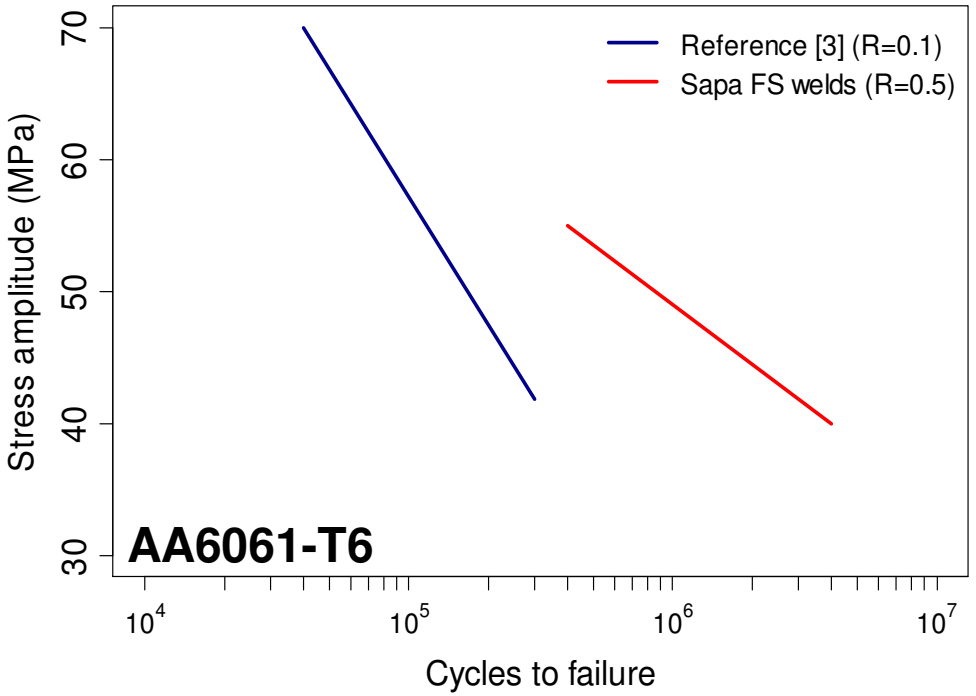
3.7 Fatigue: Production welds in AA6061-T6 vs. AA6082-T6

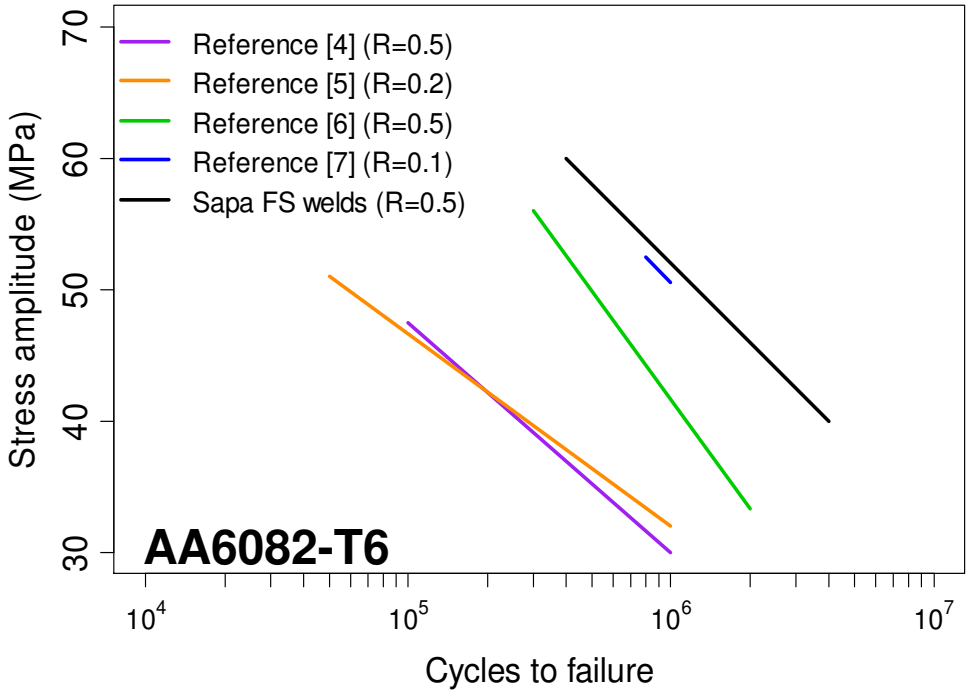
- The scatter of the fatigue data in AA6082-T6 was smaller than in AA6061-T6.

- The difference between the stress-life curves of production welds in AA6061-T6 and AA6082-T6 was not statistically significant.



3.8 Fatigue: Production welds vs. results from other publications





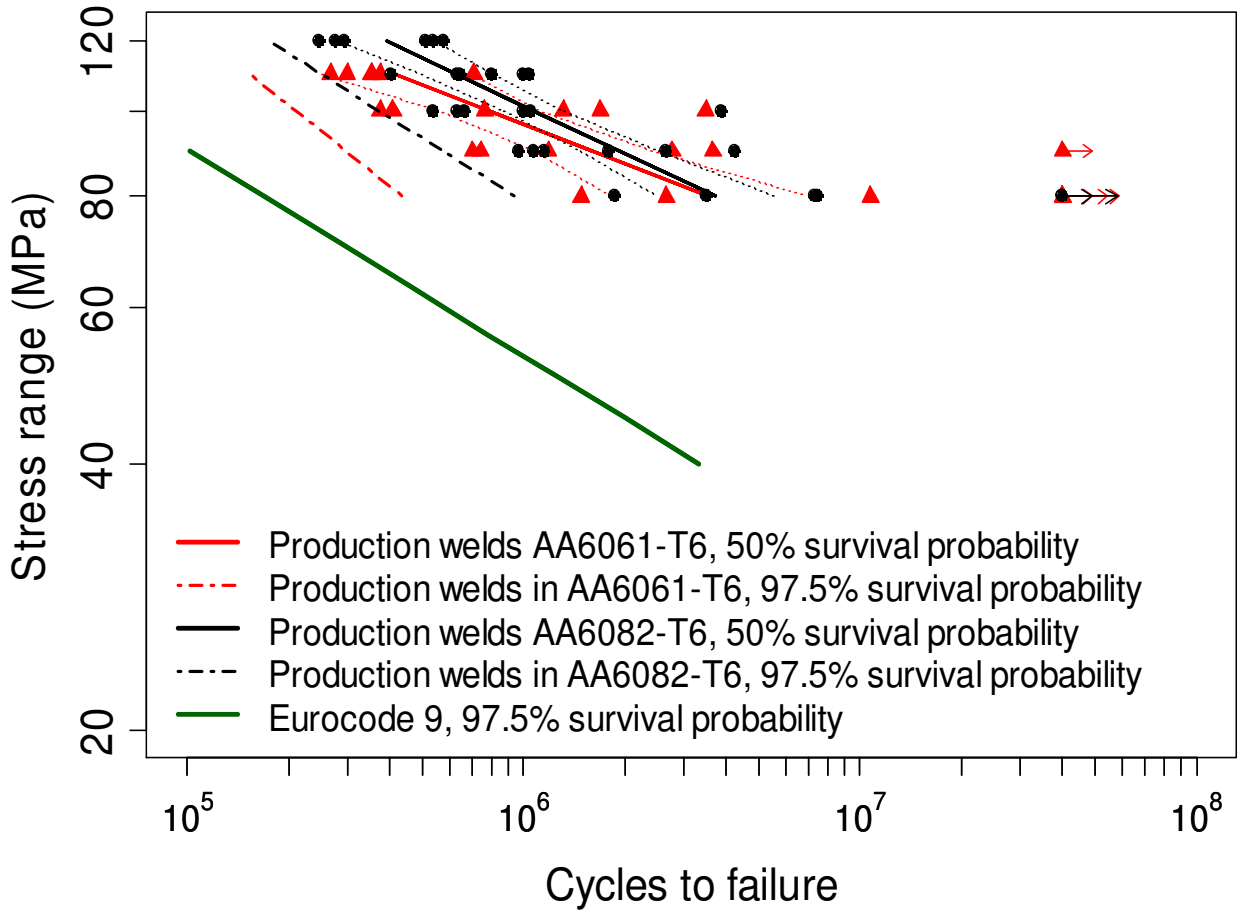
- All fatigue tests performed in axial stress-controlled mode with positive stress ratios (up to R=0.5).
- R=0.5 is the severest stress ratio.
- Considering the differences in stress ratios, Sapa FS welds show excellent fatigue strengths.

3.9 Fatigue: Production welds vs. design curves from Eurocode 9 [8]

- The design curve from Eurocode 9 gave very conservative fatigue life when compared to the production welds.

- Other authors have reported similar results.

- The small scatter in the fatigue data in the production welds in AA6082-T6 represents a design advantage as compared to AA6061-T6.



4. Conclusions (I)

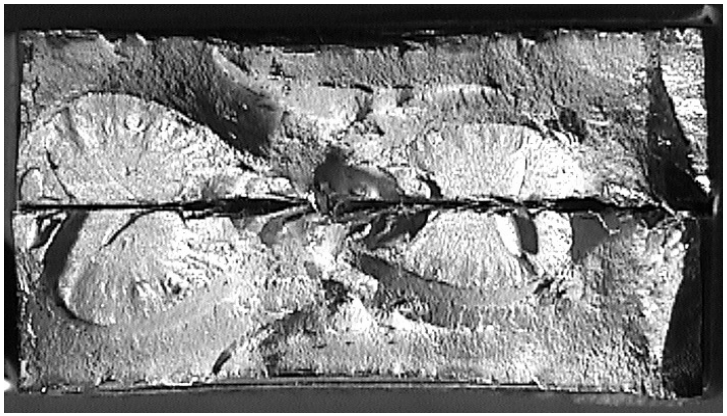
The following conclusions can be drawn from this investigation:

- The joint efficiencies of the production welds were similar (77% and 79%)

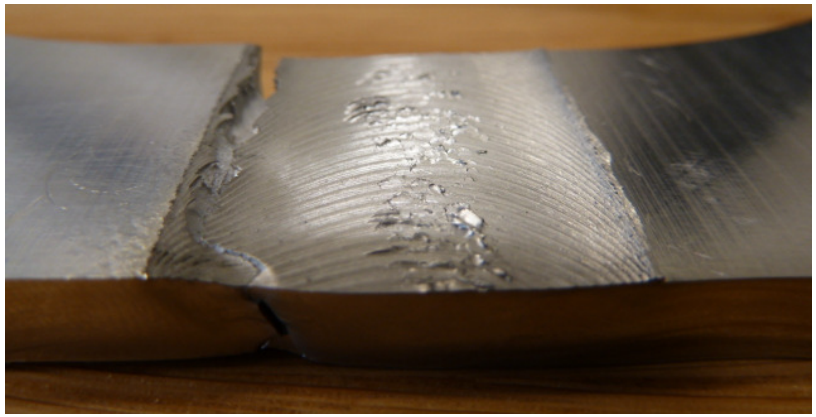
- The fatigue life of FS welds in AA6061-T6 with cracks that had initiated in the corners or in the root side were shorter than the fatigue life where the crack had started in the weld surface.

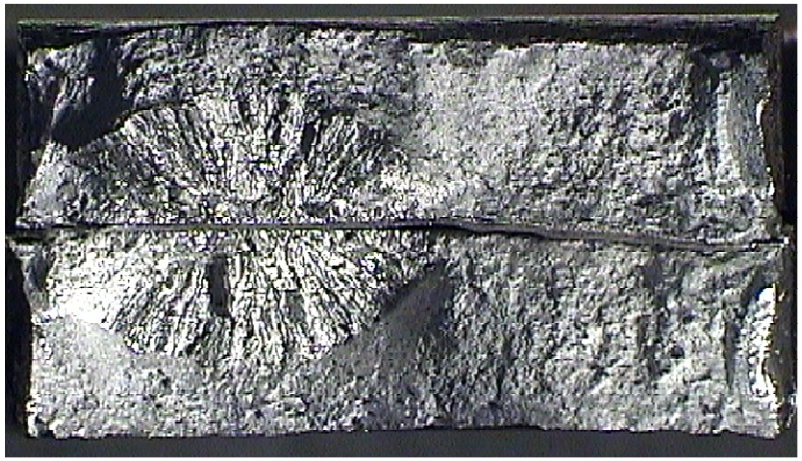
- There was no correlation between the fatigue life and the crack initiation sites in FS welds in AA6082-T6.

- Surface galling of the weld surface of FS welds in AA6082-T6 did not reduce the average fatigue strength.



4. Conclusions (II)





- There was no statistically significant difference between the fatigue strengths of the FS welds in AA6082-T6 and AA6061-T6.
- The smaller scatter in the fatigue life of production welds in AA6082-T6 represents a design advantage as compared to AA6061-T6.
- Sapa FS welds made in full scale production showed excellent fatigue strengths when compared to results published in other articles.
- The design curves from Eurocode 9, which are valid for fusion welds, underestimate the superior fatigue strength of the FS welds.

5. References

[1] S. Kahl. “The influence of small voids on the fatigue strength of friction stir welds in the aluminium alloy AA6061-T6”. Heron, Vol 55 (2010).

[2] S. Kahl. “Fatigue strength of friction stir welds in aluminium alloy AA6082-T6”. 8th International TWI Friction Stir Welding Symposium (2010).

[3] P. M. G. P.Moreira, V. Richter-Trummer, P. M. S. T. de Castro. “Fatigue Behaviour of FS, LB and MIG Welds of AA6061-T6 and AA6082-T6”. Solid Mechanics and Its Applications 152 (2008).

[4] P. J. Haagensen, O.T. Midling, M. Ranes. ”Fatigue performance of friction stir butt welds in a 6000 series aluminum alloy”. International Journal of Fatigue 18 (1996).

[5] A. Cirello, G. Buffa, L. Fratini, S. Pasta. ”AA6082-T6 friction stir welded joints fatigue resistance: influence of process parameters”. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 220 (2006).

[6] M. Ericsson, R. Sandström. ”Fatigue performance of friction stir welded AlMgSi alloy 6082”. ALUMINIUM Volume 77 (2001).

[7] T. L. Dickerson, J. Przydatek. “Fatigue of friction stir welds in aluminium alloys that contain root flaws”. International Journal of Fatigue 25 (2003).

[8] EN 1999-1-3 “Eurocode 9 – Design of aluminium structures – Structures susceptible to fatigue”. European Committee for Standardization, (2006).

If you have any questions regarding this presentation or if you would like to have a copy of the complete paper, please contact Jesus Mendoza.

Email: jesus.mendoza@sapagroup.com
Telf: +46 733 10 22 38