The role of existing corrosion on fatigue crack initiation in 2xxx and 6xxx aluminum laser beam welds

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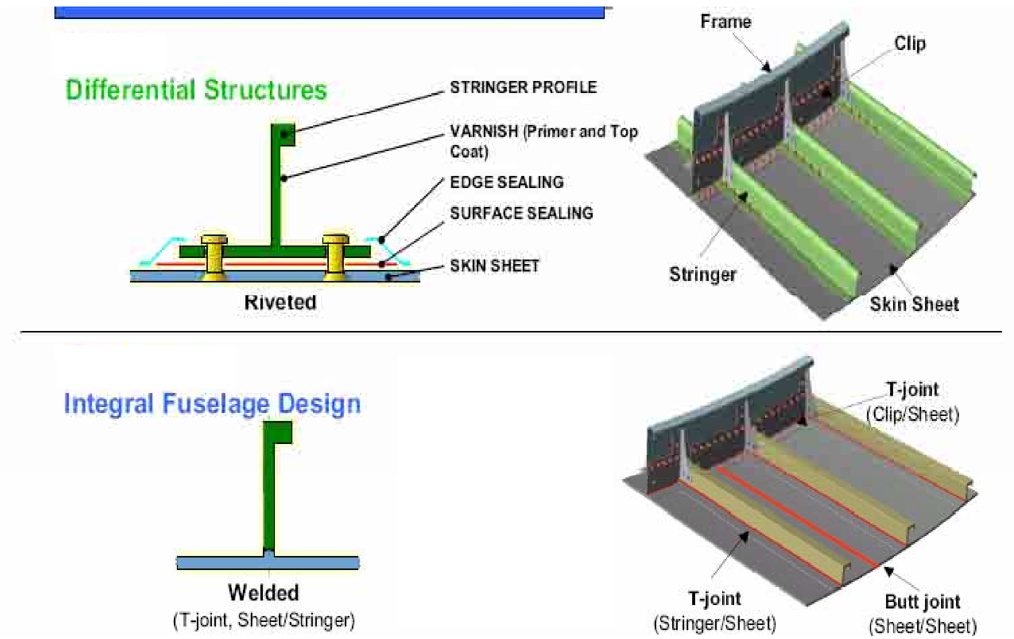
DEVELOPMENT OF SHORT DISTANCE WELDING CONCEPTS FOR AIRFRAMES (WELAIR), (CEC STREP) 2004-2007

- **Integral airframes offer improved weight and cost efficiency compared to differential (riveted) structures**



Critical

Increasing service life

Corrosion

Fatigue Performance

Overview

- **Investigation of Corrosion behavior in 2xxx and 6xxx aluminum LBW**
- **Investigation of role of heat treatment on Corrosion behavior in 2xxx LBW**
- **Investigation of Fatigue crack initiation of corroded and uncorroded 2xxx and 6xxx LBW**

Results on:

- **Exposure of laser beam welded samples to laboratory corrosion environment**
- **Metallographic corrosion characterization**
- **Examination of the influence of heat treatment on the corrosion behaviour**
- **Fatigue testing to study effect of corrosion on fatigue crack initiation**
- **Fractographic investigation to obtain fatigue crack initiation sites and crack path**

Material 1

2139 AA laser beam welds in T3 and T8 condition

Heat treatment

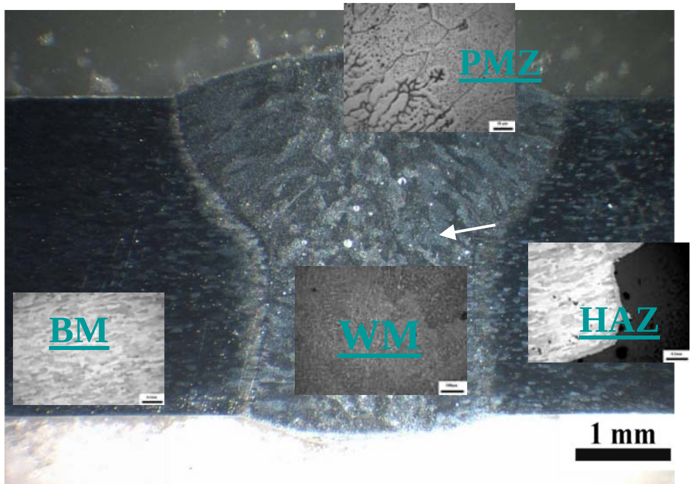
T3: ST, quenching, cold work, natural ageing, 3 % pre-strain

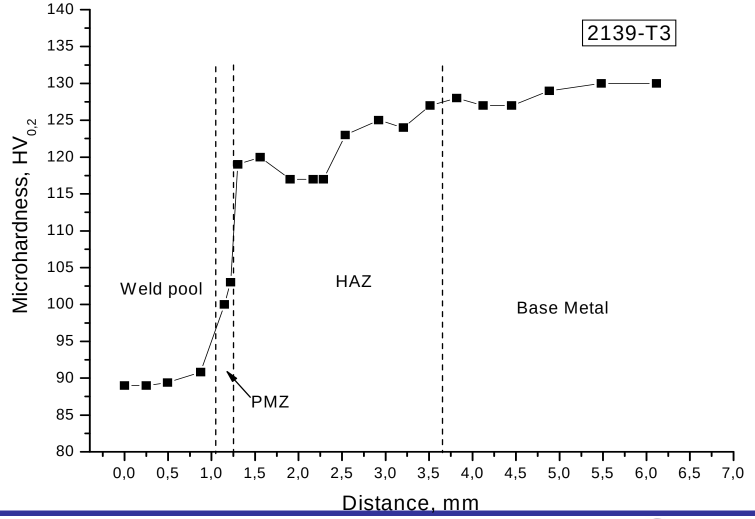
T8: ST, quenching, artificial ageing, 5% pre-strain

Chemical composition

Si	Fe	Cu	Mn	Ag	Mg	Zn	Ti	Zr
0,04	0,06	4,79	0,3	0,34	0,45	<0,01	0,05	0,01
0,04	0,06	4,79	0,29	0,34	0,45	<0,01	0,05	0,01

Weld section

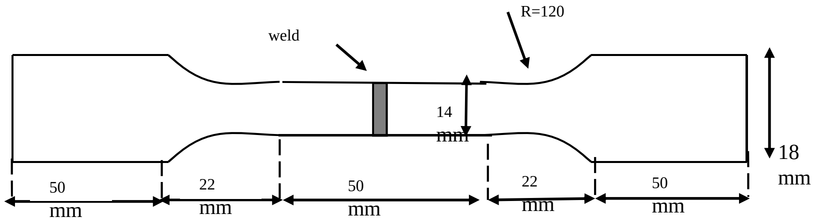




Corrosion exposure

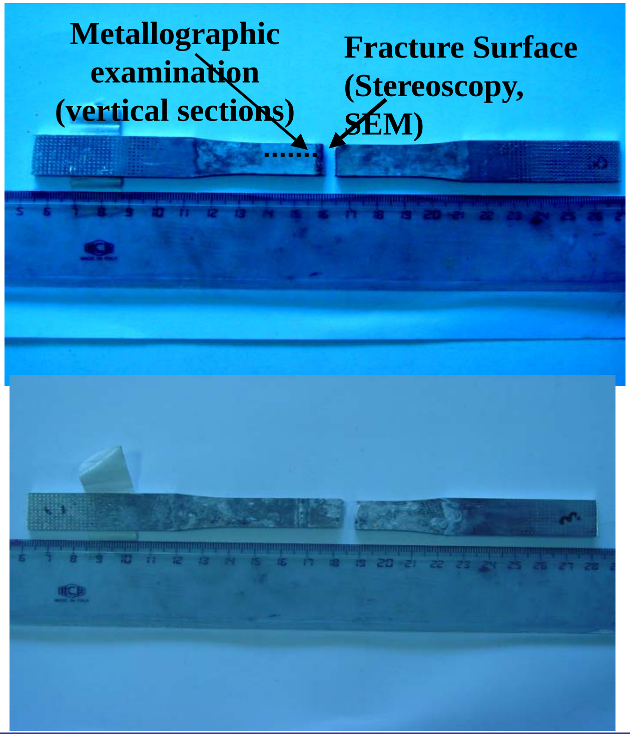
Corrosion environment: Salt Spray 720 hrs ASTM B117, Nacl 5%

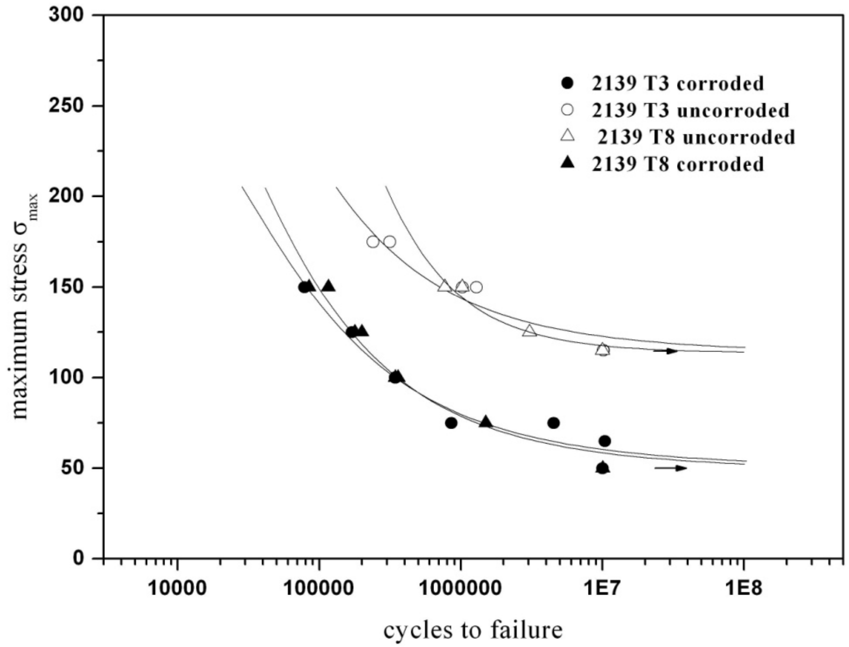
2139 - Fatigue behaviour of uncorroded and corroded welds



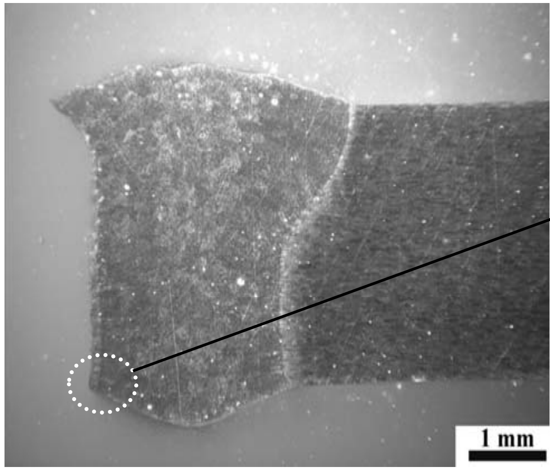
R=0.1

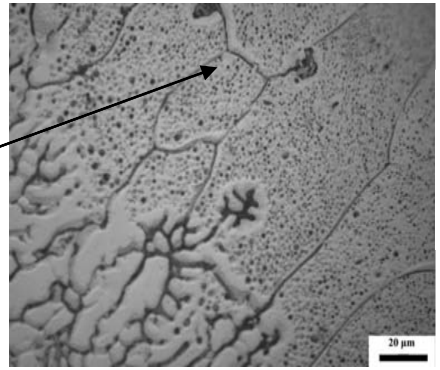
Frequency: 25 Hz

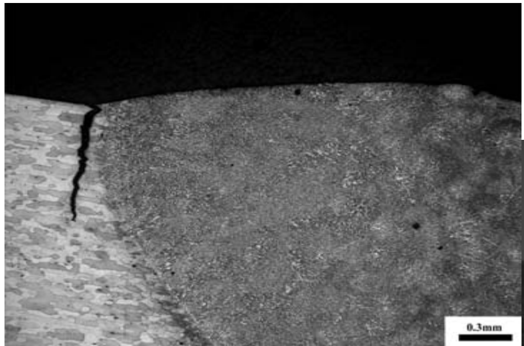


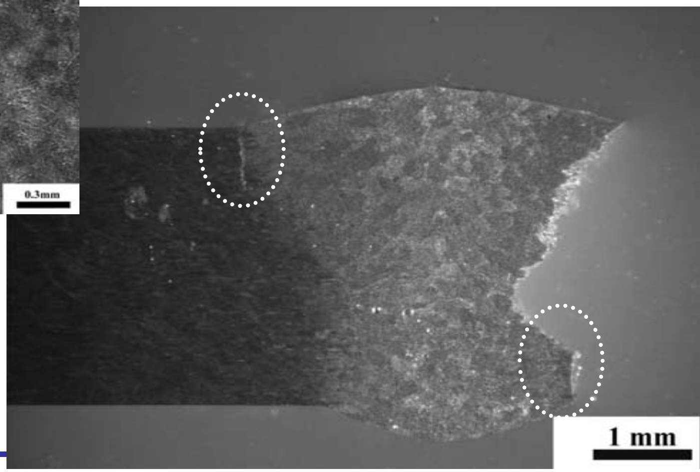


2139 T3 – Crack initiation and fracture path (uncorroded)



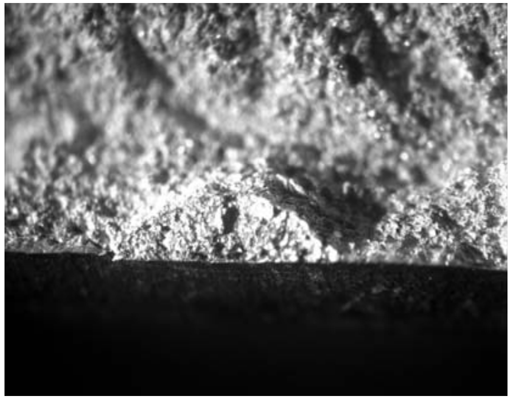


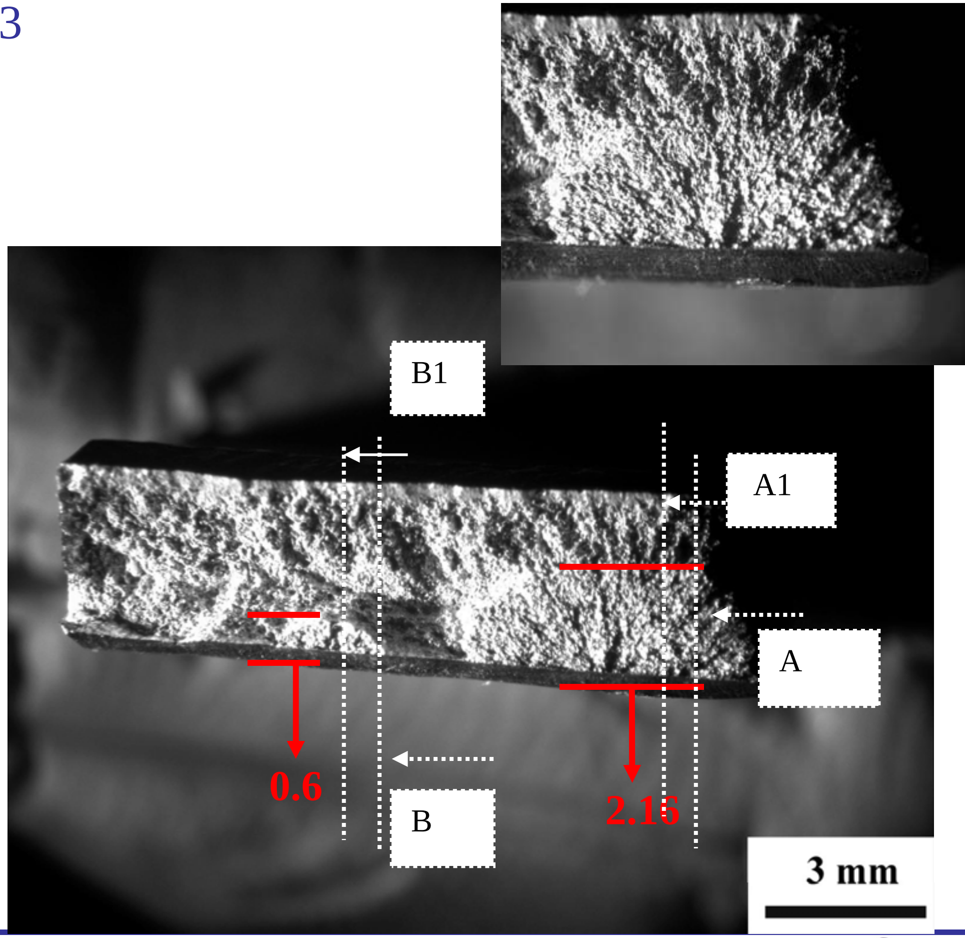




2139 T3 – Fractographic analysis (uncorroded)

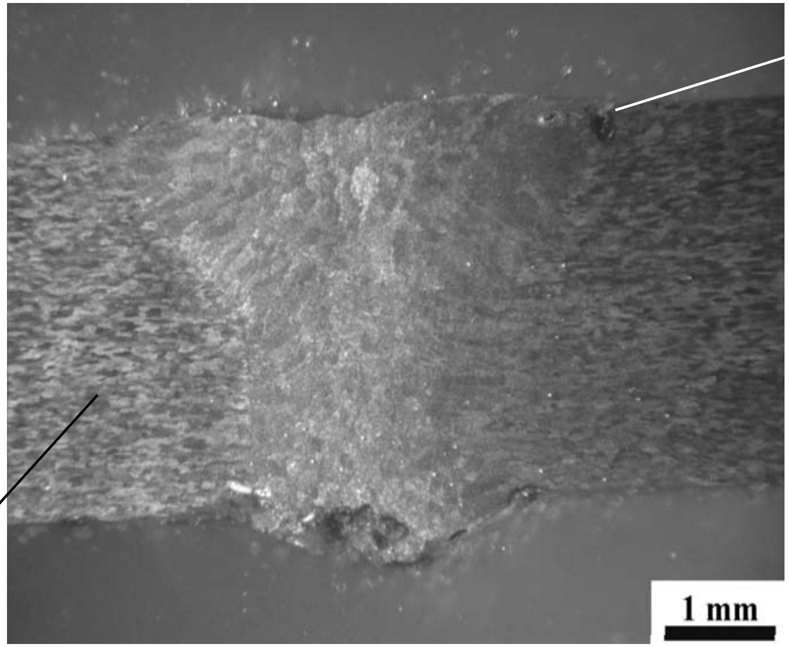
2139 T3 σ_{max}=150, Nf=1,025,613

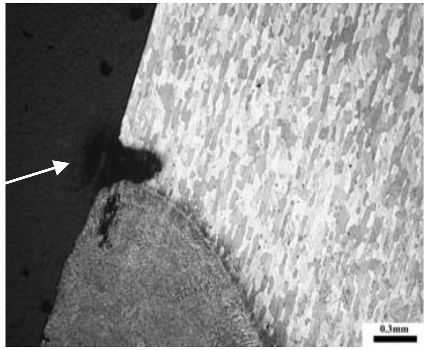




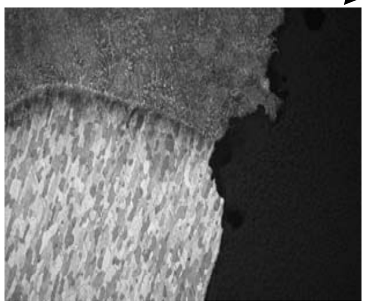
2139 T3 - Corrosion behavior

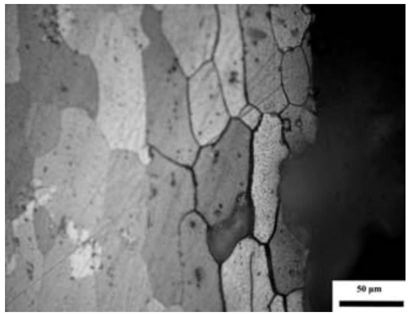
Weld area significantly corroded-Base metal minor corrosion attack





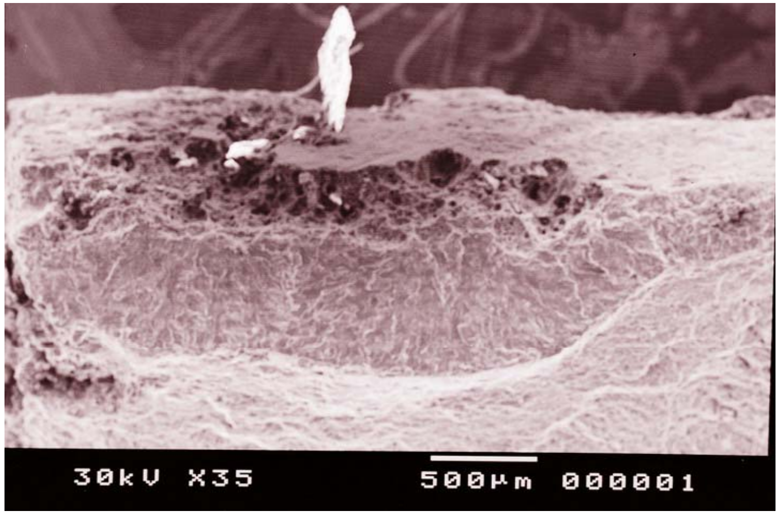
Localized galvanic couple



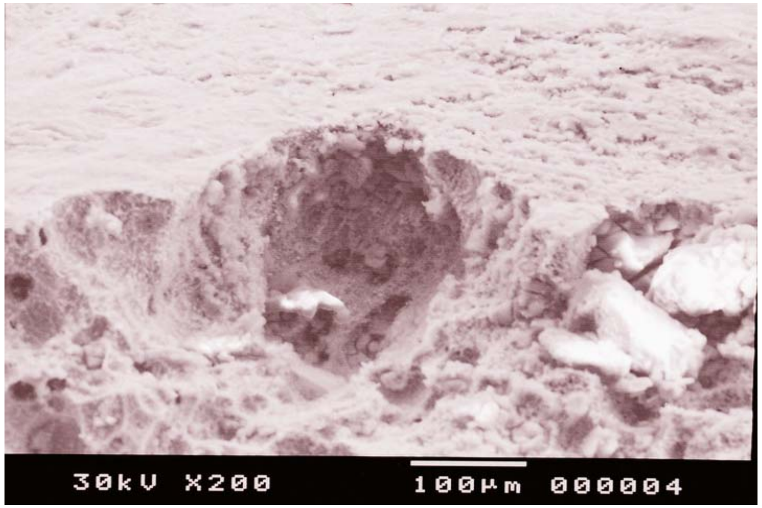


Intergrannular corrosion

2139 T3 – Crack initiation from corrosion pits



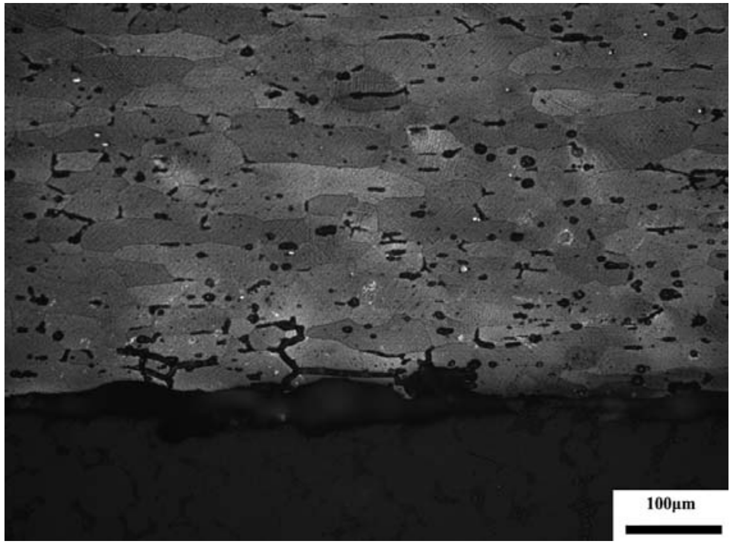
Fatigue section



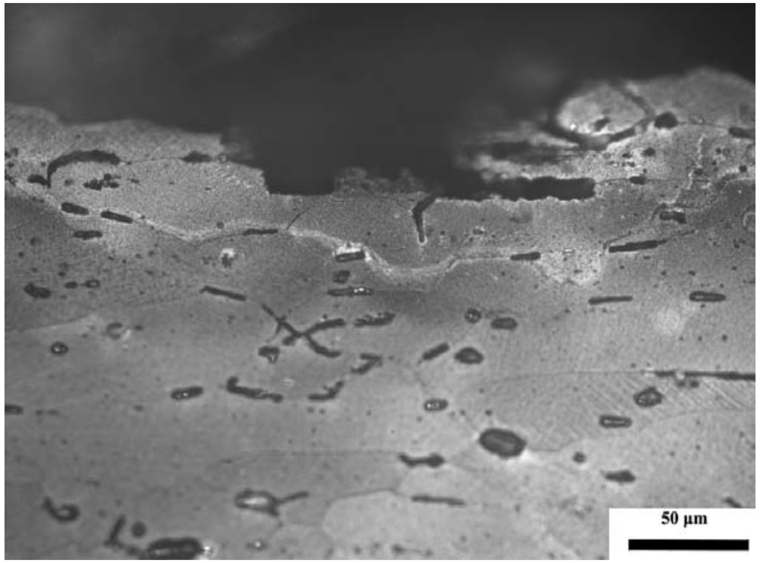
Initiation site -corrosion

2139 T8 – Corrosion characterization

Corrosion behaviour reversed to T3: Corrosion damage detected in base metal – Weld area insignificantly corroded

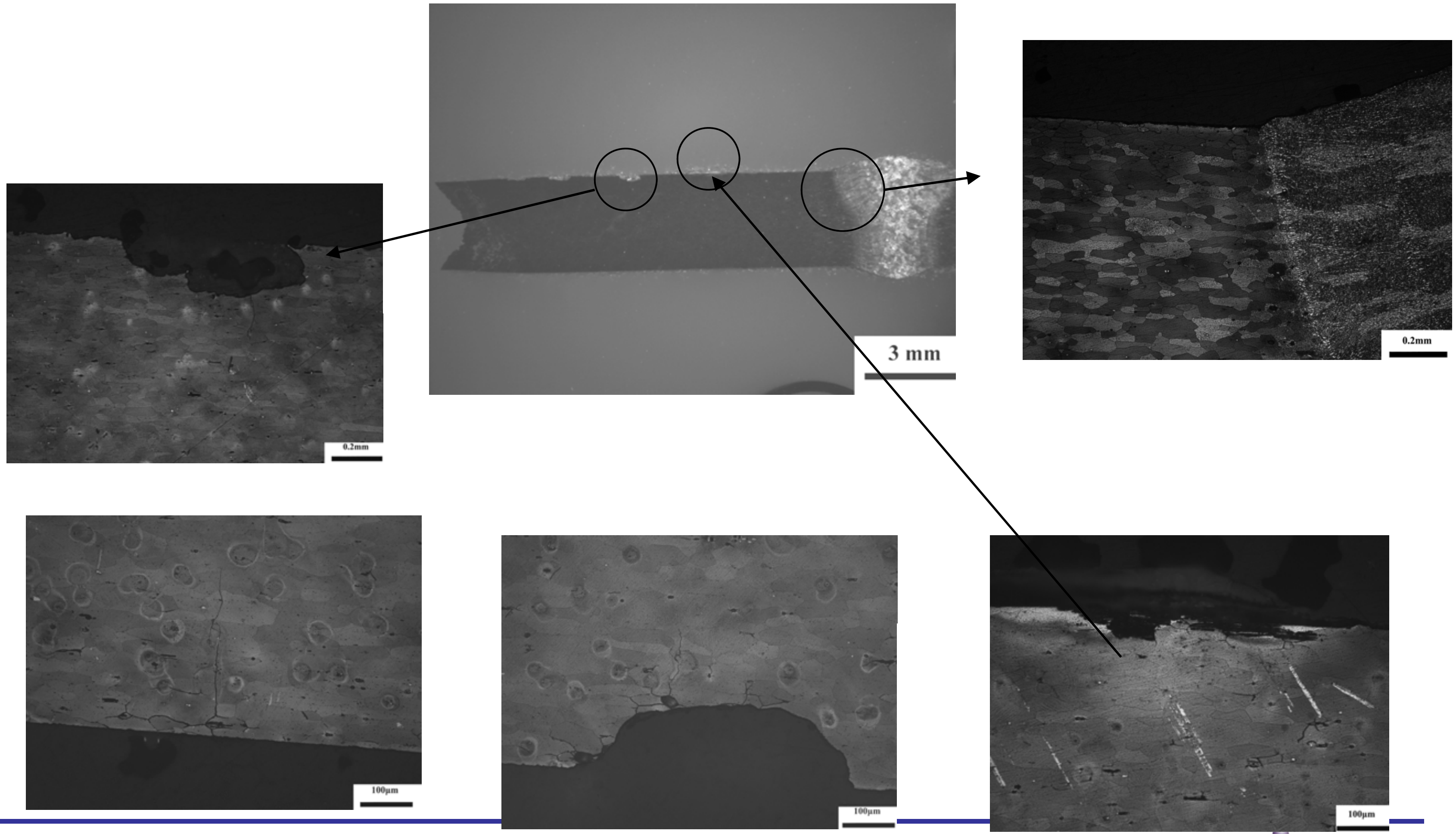


B: Intergranular corrosion

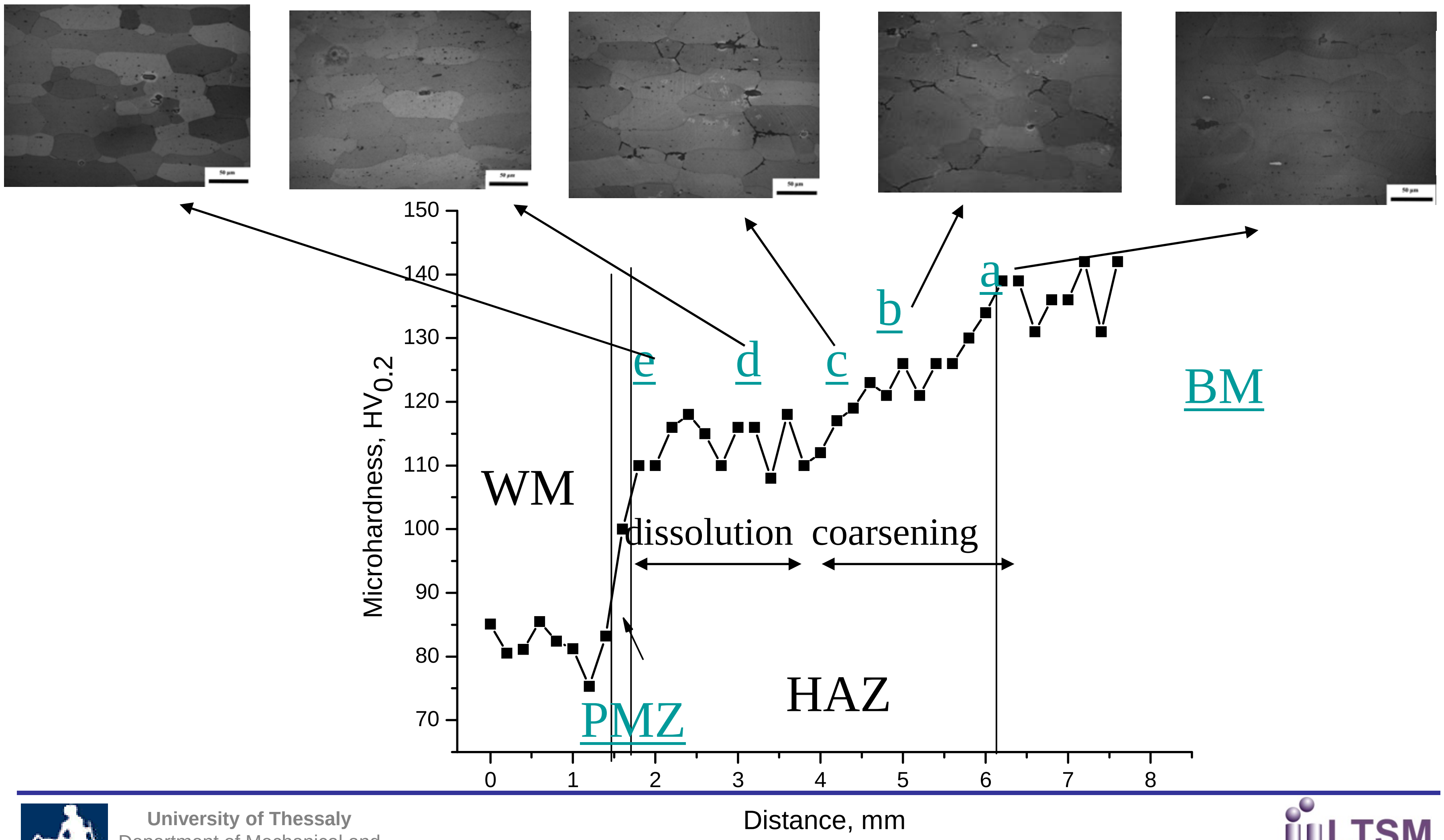


exfoliation corrosion

2139 T8 – Crack initiation and fracture path (corroded)

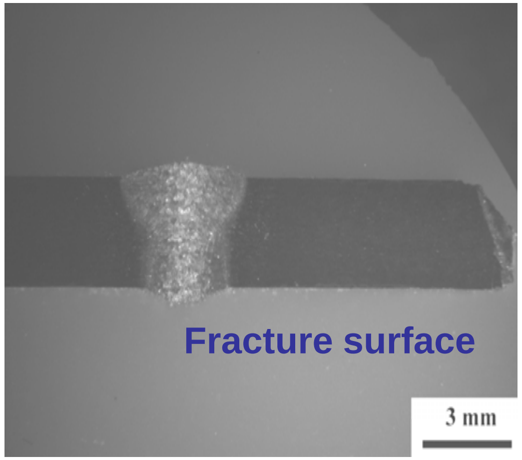


2139 T8 - Microstructural gradient in the HAZ

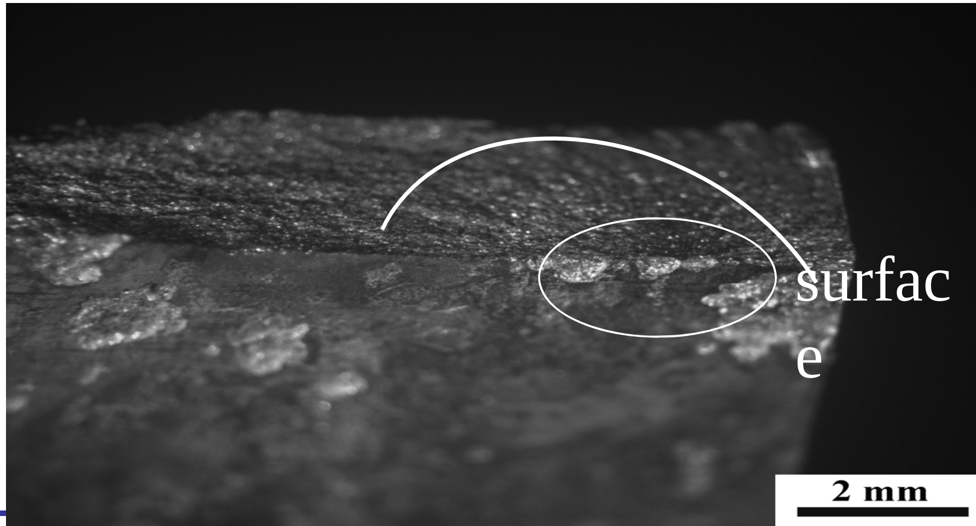


2139 T8 - Fatigue initiation at corrosion pit and fracture path

A: Secondary crack initiates from corrosion pit 8.6 mm from the WM centre



Failure (Distance from WM centre, mm)	1st Corrosion pit (Distance from WM centre, mm)	
	upper	bottom
9.3	8.6	-
13.2	6.6	6.6
5.4	4.8	3.6
12.6	10.5	8.4



Conclusions

In all cases examined corrosion exposure leads to degradation of fatigue perfomance of the welds. More specifically

•2139 T3 :

- **Increased susceptibility of the weld area to corrosion damage**
- **Crack initiation occurs at geometrical discontinuities induced by weld reinforcement**
- **Corrosion pits at the WM/BM interface act as additional stress raiser sites reducing the crack initiation stage**
- **Fatigue crack initiates and propagates through the weaker material (PMZ zone)**

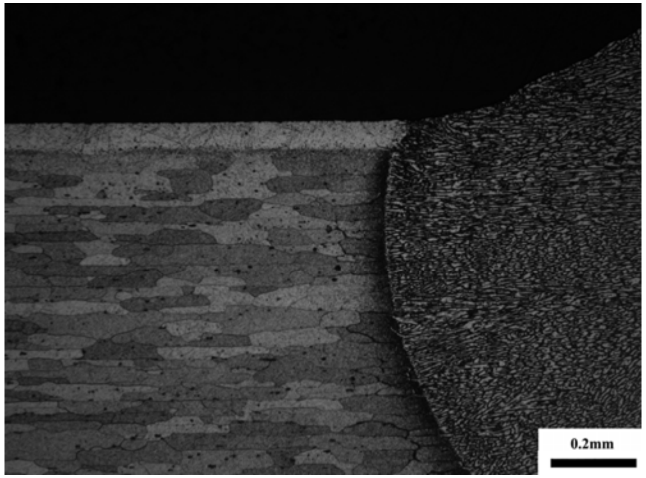
2139 T8 :

- **Corrosion was limited to the base metal possibly due to existing grain boundary phases**
- **Crack initiates at corrosion pits in the base metal and fracture appears at the base metal**

Material 2

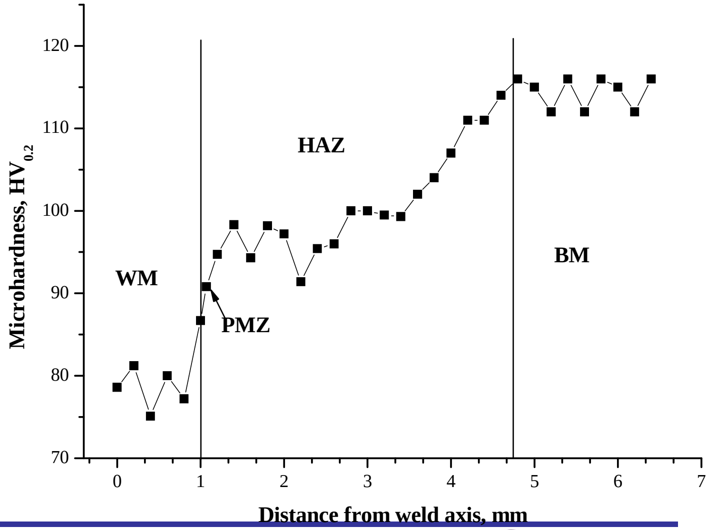
Alclad 6154 AA laser beam welds in T4 condition

Weld section



Heat treatment

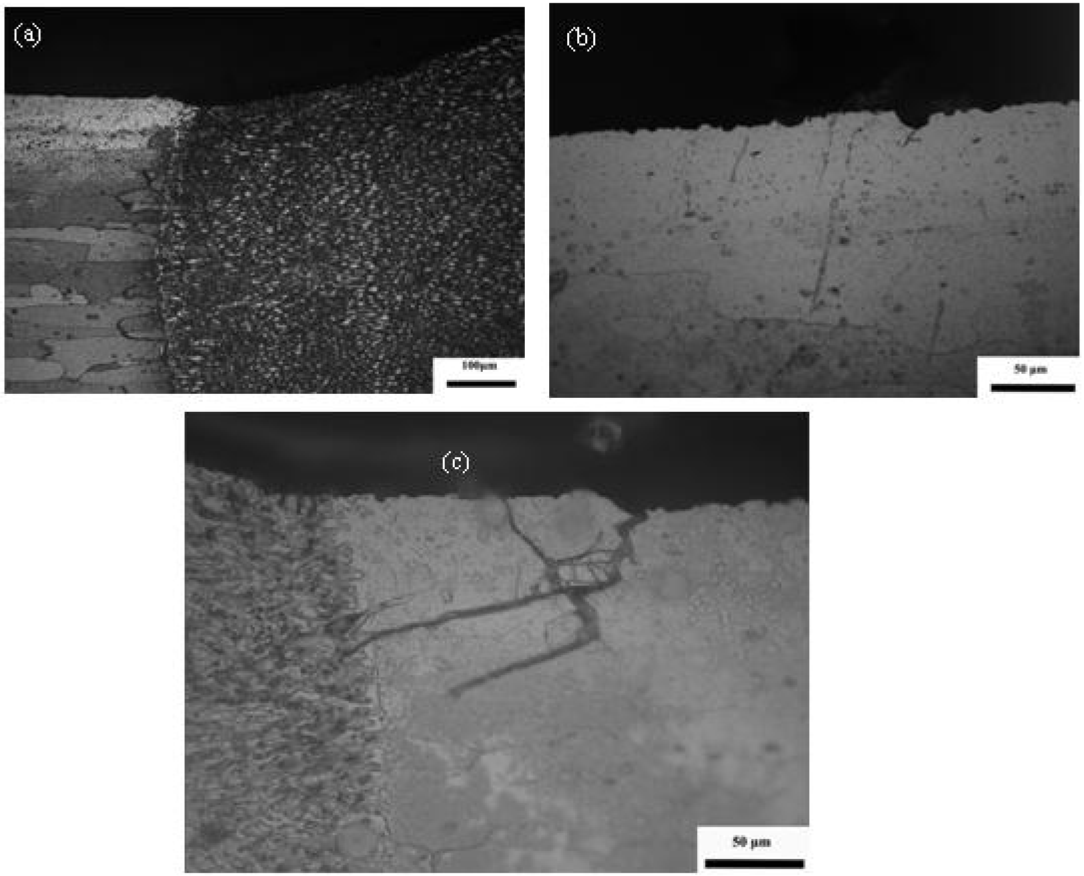
T4 : solution heat treatment and natural ageing to substantially stable condition



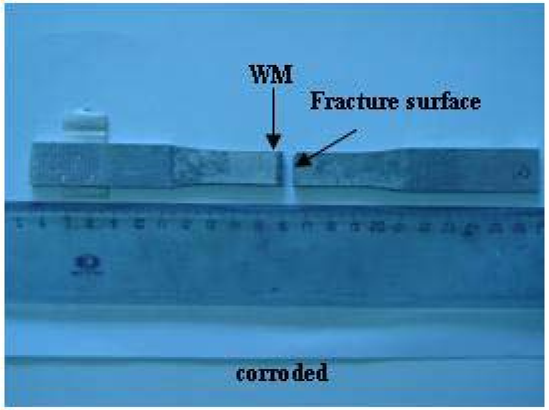
Chemical composition

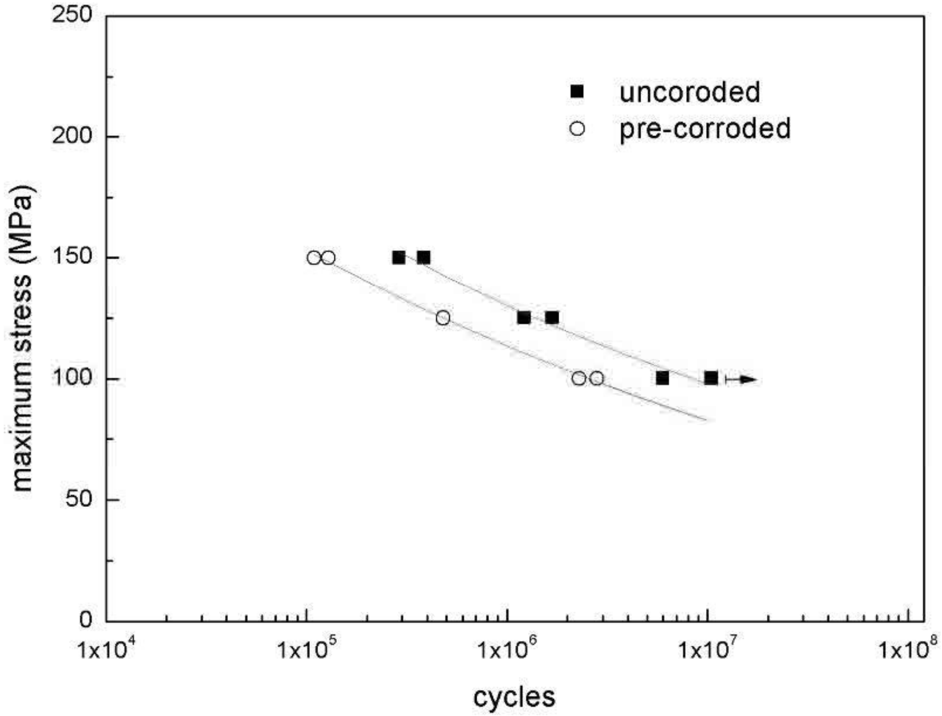
Si	Mg	Cu	Fe	Mn	Cr	Zn
1	0.9	0.9	0.1	0.55	0.125	0.4

6154 T4 - Corrosion behavior

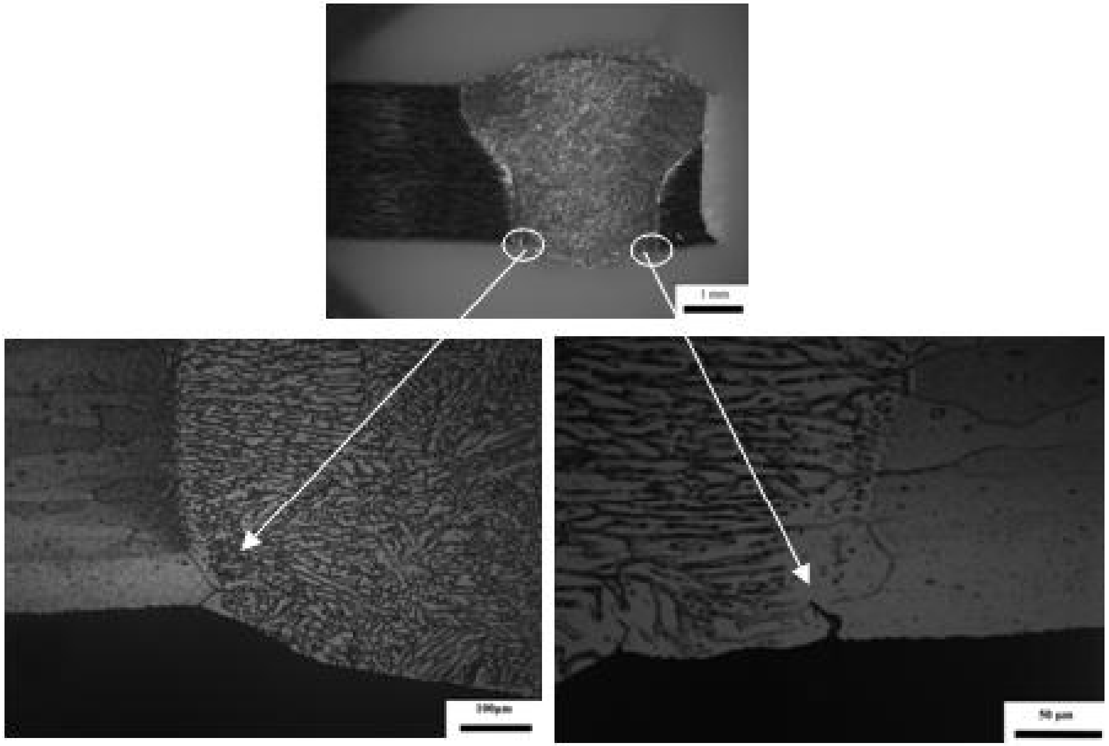


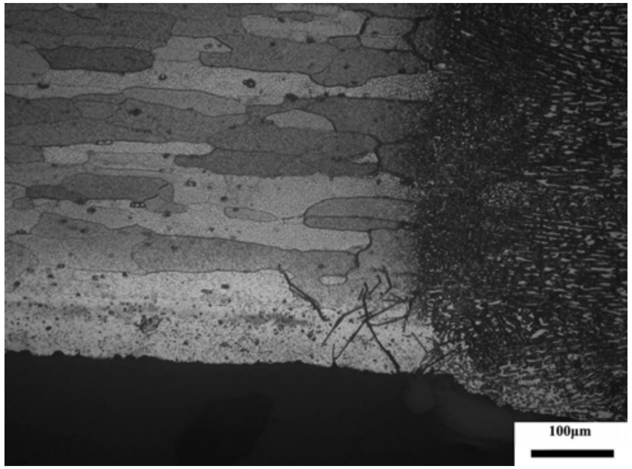
6154 T4 - Fatigue behavior

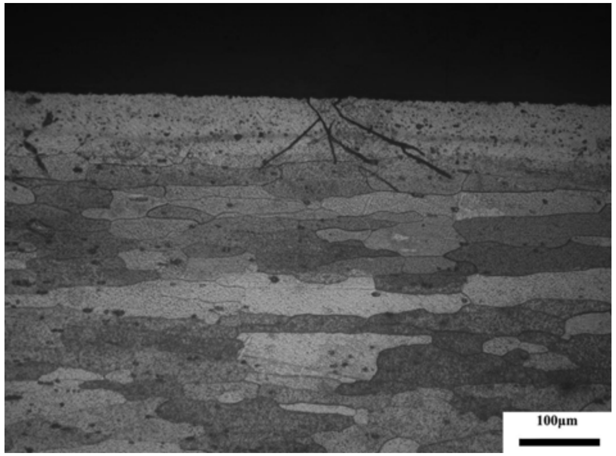




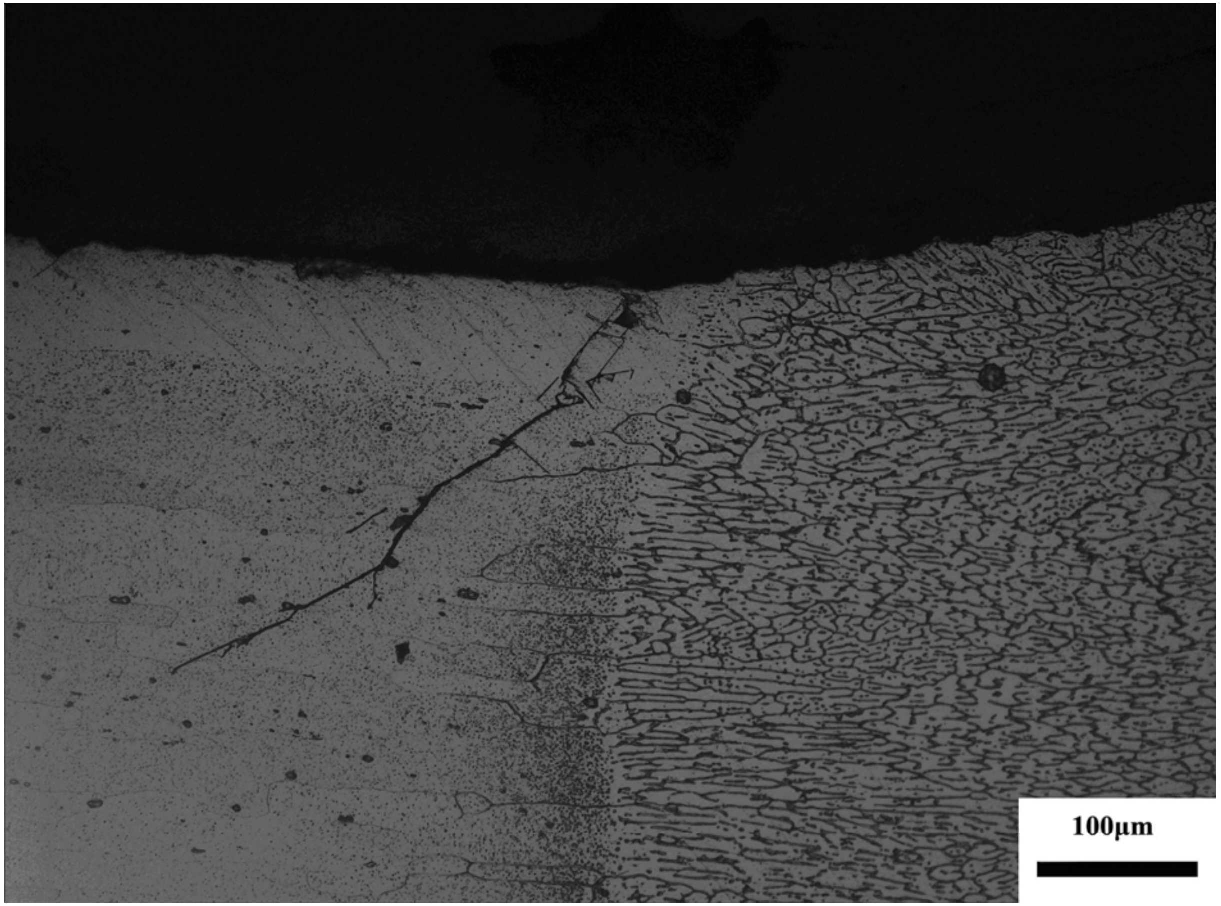
6154 T4 - Fatigue behavior





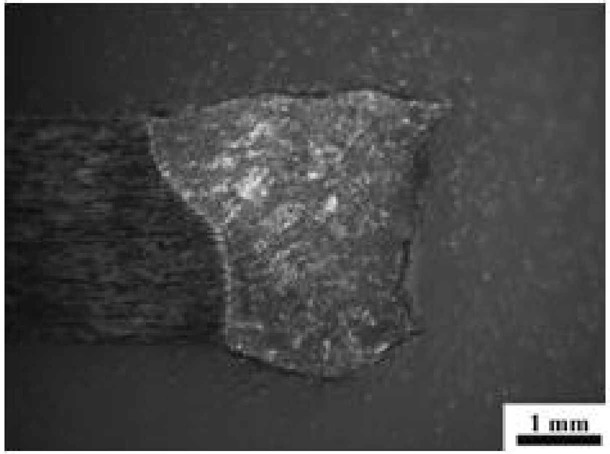


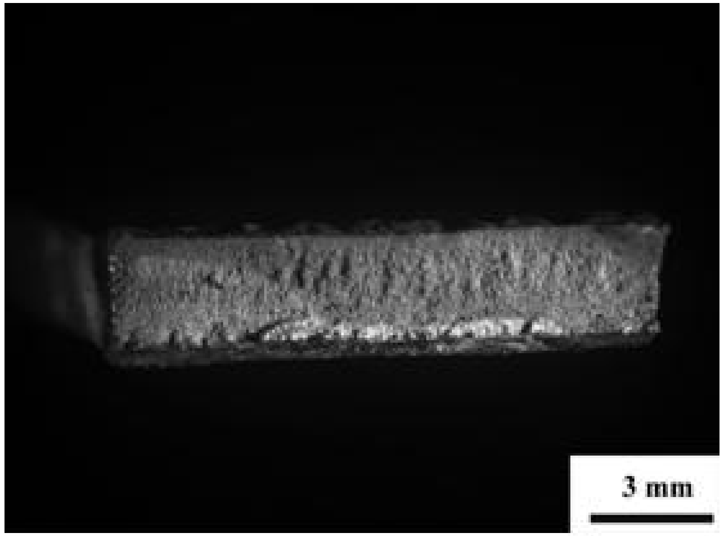
6154 T4 - Corrosion behavior

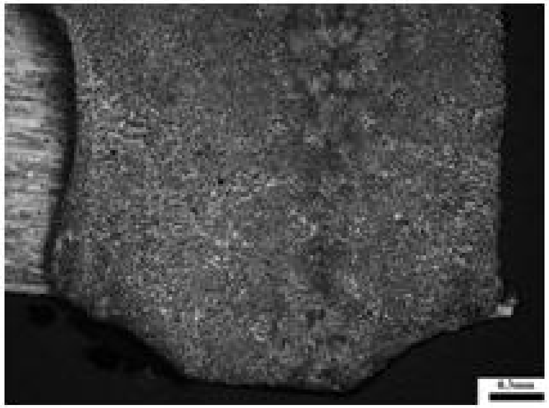


Crack initiation at the bottom of corrosion pit at the PMZ

6154 T4 - Corrosion behavior

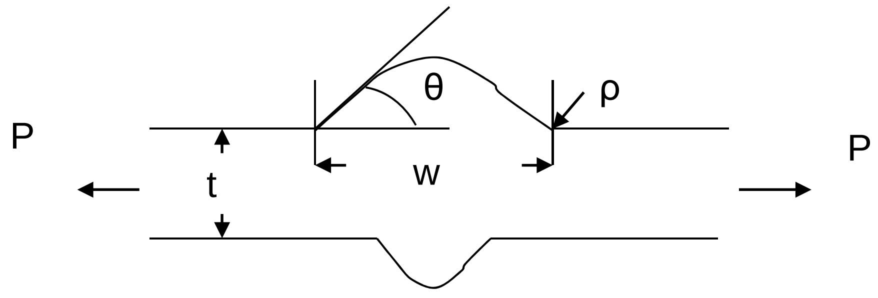






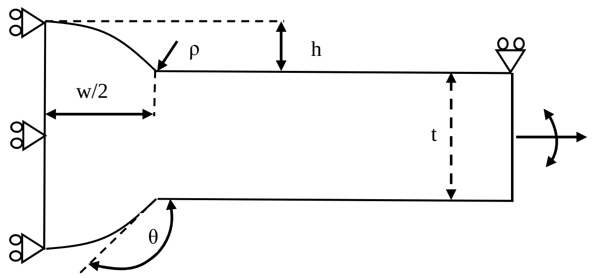
6154 T4 - Estimation of local stress at crack initiation location

Estimation of local stress at weld toe



$$K_{t1} = \frac{4\left(2\tan\frac{\theta}{2}\right)^{1-2m}}{2\theta + \sin(2\theta)}\left(\frac{t}{4\rho}\right)^{m}$$

Lehrke et al. [21,22]



$$K_{t2} = \left[1 + f(\theta)\{g(\rho) - 1\}\right] C(a/t)$$

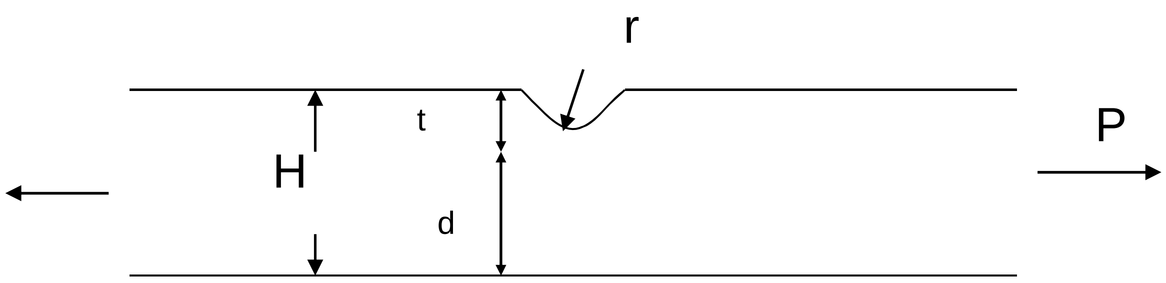
Ushirokawa et al. [23]

[21] Brandt U, Lehrke H-P, Sonsino CM, Radaj D. (1999)Anwendung des Kergrundkonzeptes fu¨r die schwingfeste Bemessung von Schweißverbindungen aus Aluminiumknetlegierungen. Fraunhofer-Institut fuer Betriebsfestigkeit (LBF), Darmstadt. Final-Report
[22] Lehrke H-P. (1999) Berechnung von formzahlen fuer Schweißverbindungen Konstruktion 51(1/2):47–52
[23] 0. Ushirokawa and E. Nakayama (1983) Stress Concentration Factor at Welded Joints. Ishikawaj ima- Harima Gihou (Technical Report) 23(4) (in Japanese).

Estimation of local stress at weld toe

Parameter	Thickness t (mm)	Radius ρ(mm)	Angle θ (Lehrke)	Angle θ (Ushirokawa)	Parameter m [16]	Reinforcement width W(mm)
Lehrke	2.8	0.5	24^0		0.2145	2.8
K_{t1}	1.62					
Ushirokawa	2.8	0.5		156^0		2.8
K_{t2}	1.54					

Estimation of local stress around corrosion pit



equation suggested by Cole et al.[24]:

$$Kt_n = 3.065 - 8.871(t/H) + 14.036(t/H)^2 - 7.21(t/H)^3$$

[24] Cole A. G. and A. F. C. Brown (1958) Photoelastic Determinationof Stress Concentration Factors Caused by a single U-notch on one side of a Plate in Tension. Journal of Roy. Aeron. Soc. 62: 597-598

Combined stress concentration (weld toe and corrosion pit)

$$K_{tc} = K_t K_{tn}$$

Ktc=4.8 (corroded specimens)

$$\sigma_{localpit} = \sigma_{macro} K_{tc}$$

Kt = 1.6 (uncorroded specimens)

Fatigue notch sensitivity

$$q = \frac{K_f - 1}{K_{tn} - 1} = 0.125$$

Conclusions

The influence of salt fog corrosion on the fatigue behaviour of cladded 6156 T4 aluminum alloy laser welded joints was investigated.

The main conclusion of the work is that despite the general corrosion protection offered by the clad layer, the localized attack of the clad layer, in the form of pitting corrosion, leads to inferior fatigue performance.

In all cases the weld reinforcement acts as a significant stress concentration site for fatigue crack initiation.