

Effect of Sensitization on the Microstructure and the Mechanical Properties of 5xxx Aluminum Alloys

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ABSTRACT

5xxx aluminum alloys are typically used for storage tanks, pressure vessels, and marine service applications that require a weldable and moderate-strength alloy with good corrosion resistance. However, they can become susceptible to intergranular attack, intergranular stress corrosion cracking, and reduced ductility/toughness when they are exposed to temperatures ranging from 50°C to 200°C for sufficiently long periods of time. This phenomenon is known as "sensitization" and is associated with the precipitation of Mg-rich phases on grain boundaries during elevated-temperature exposure. In order to investigate the effects of sensitization on the 5xxx alloys, 5456 (H116) and 5083 (H116) and a 5456 alloy removed from service after a 15-year exposure have been analyzed. Metallographic observations have been used to investigate the grain size and the distribution of secondary phases, while TEM/STEM have been used to analyze precipitates in the grains and/or on grain boundaries. The mechanical properties of these alloys have been investigated at room temperature in the as-received and sensitized (i.e. after 15 years service) conditions using a combination of tension testing, fracture toughness testing, and fatigue crack growth experiments. High strain rate experiments are also planned to investigate the toughness under ballistic loading conditions.

EXPERIMENTAL

Materials

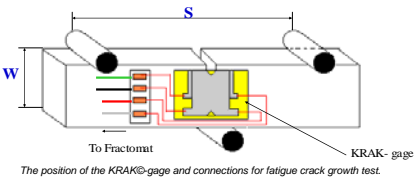
- Commercial 5456 (H116) and 5083 (H116) aluminum alloys
- Commercial 5456 aluminum alloy removed from service after a 15-year exposure

Microstructure

- Metallurgy
 - AA 5456 etched by Keller's Reagent
 - AA 5083 etched by a modified Poulton's Reagent
- TEM/EDS
 - Samples prepared by mechanical polishing and ion milling
 - Observation and analysis conducted on Philips CM20 at 200kV
- STEM/EDS
 - Observation and analysis conducted on FEI Tecnai F30 at 300kV

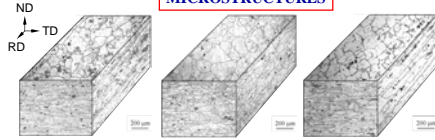
Mechanical Testing

- Hardness: Rockwell hardness tester (1/16" ball, 100Kg).
- Tension Test: dog bone sample, displacement rate of 0.05mm/min, Instron testing machine.
- Notched toughness, fatigue precracked toughness, fatigue crack growth measured.
- Toughness and fatigue crack growth tests: 3PB specimen: 200 µm notch radius.
- MTS 20 Kip closed loop servohydraulic machine, MTS 458.20 controller, FTA control software.
- Specimens fatigued at 20 Hz, sinusoidal wave, load ratio (R) =0.1.
- Fatigue crack length measured with metallic foil KRAK® (KG-A05)-gages monitored by a Fractomat model 1288 crack measurement system.



RESULTS

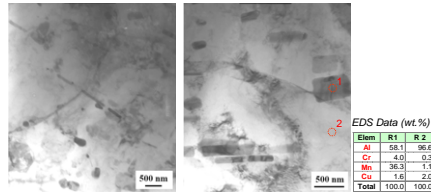
MICROSTRUCTURES



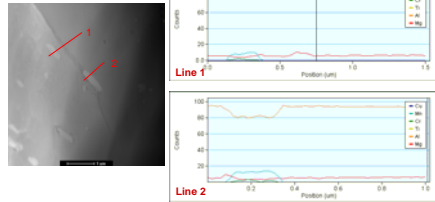
Metallographic pictures showing grain boundaries in three dimensions.

Grain Size Measurement (µm)

Sample	Direction	ND Plane	TD Plane	RD Plane
5456(H116)	RD	20.3 ± 4.2	30.7 ± 4.7	
	TD	15.1 ± 2.1		25.3 ± 3.3
	ND		11.5 ± 0.8	11.7 ± 1.2
5456(Sensitized)	RD	18.0 ± 3.7	16.8 ± 3.4	
	TD	17.8 ± 2.3		18.3 ± 2.9
	ND		8.1 ± 1.2	8.3 ± 0.9
5083(H116)	RD	18.3 ± 1.9	35.0 ± 8.0	
	TD	13.8 ± 2.0		30.6 ± 9.9
	ND		9.3 ± 1.2	10.2 ± 0.9
	Aspect Ratio	1.3	3.7	3.0



TEM views showing precipitation at grain boundaries and in grains. Particles are rich in Mn and Cr, analyzed by EDS.



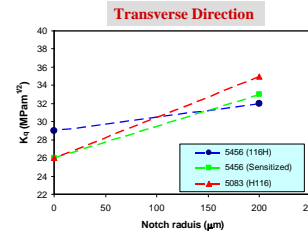
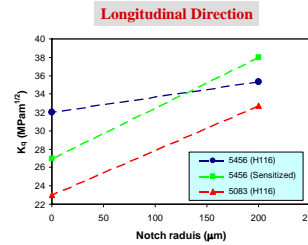
STEM view showing precipitation at grain boundary and in grain. Corresponding EDS line profiles showing particles containing much more Mn and grain boundary containing more Mg than matrix, respectively.

RESULTS

HARDNESS-TENSION

Materials	HRB	σ_y (MPam ^{1/2})	UTS (MPam ^{1/2})	EL %
5456(H116)	52.3 ± 0.6	255	357	17.2
5456(Sensitized)	36.5 ± 1.0	N/A	N/A	N/A
5083(H116)	44.5 ± 4.5	265	340	15.3

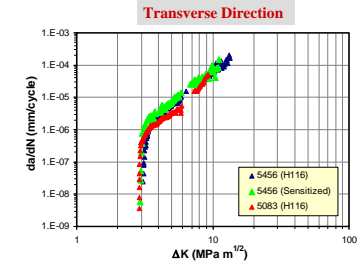
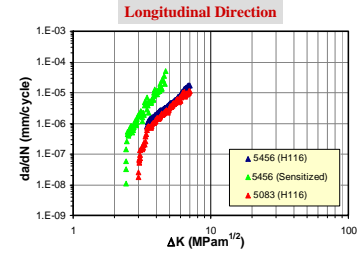
FRACTURE TOUGHNESS



- Sensitized 5456 exhibits reduced K_{IC} .
- Sensitized 5456 exhibits increased Paris slope.

RESULTS

FATIGUE CRACK GROWTH



FATIGUE CRACK GROWTH SUMMARY

ID	Testing Direction	ΔK_{th} (MPa m ^{1/2})	m	K_{IC} (MPa m ^{1/2})
5456(H116)	Longitudinal	3.0	3.6	32
5456(Sensitized)	Longitudinal	2.4	6.3	27
5083(H116)	Longitudinal	3.0	3.8	23
5456(H116)	Transverse	3.1	3.2	29
5456(Sensitized)	Transverse	2.9	3.7	26
5083(H116)	Transverse	2.9	3.0	26

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CONCLUSIONS

- Microstructures of as-received and sensitized materials quantified via metallurgy, TEM, and STEM.
- Preliminary fracture toughness and fatigue crack growth behavior characterized.
- Future work to examine high strain rate and spall behavior.