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EFFECTS OF THE SECONDARY AGING T6I4 ON FRACTURE TOUGHNESS AND FATIGUE CRACK GROWTH RESISTANCE OF AA7050 ALLOY

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INTRODUCTION

- Age hardened aluminum alloys are widely employed in aerospace industry due to their high specific strength and corrosion resistance.
- Mechanical Properties depend on the type, morphology, size, spacing and volume fraction of strenghtening precipitates.
- Aluminum alloy 7050 (AMS 4050) has been a standard material for use in fuselages, bulkheads and exterior wing skins.
- Precipitation sequence for 7xxx series is described as:
  Solid Solution$\rightarrow$ G.P. zones$\rightarrow$ metastable $\eta'$$\rightarrow$ stable η ($MgZn_2$).
- Common tempers are T7651 and T7451(Solution Heat Treated, Stress Relieved, and Overaged).
- Industrial development has put forward higher performance requirements for the Al-Zn-Mg-Cu alloys.
- Researches focused on multi-stage aging like the ‘Interrupted Aging’.

INTRODUCTION

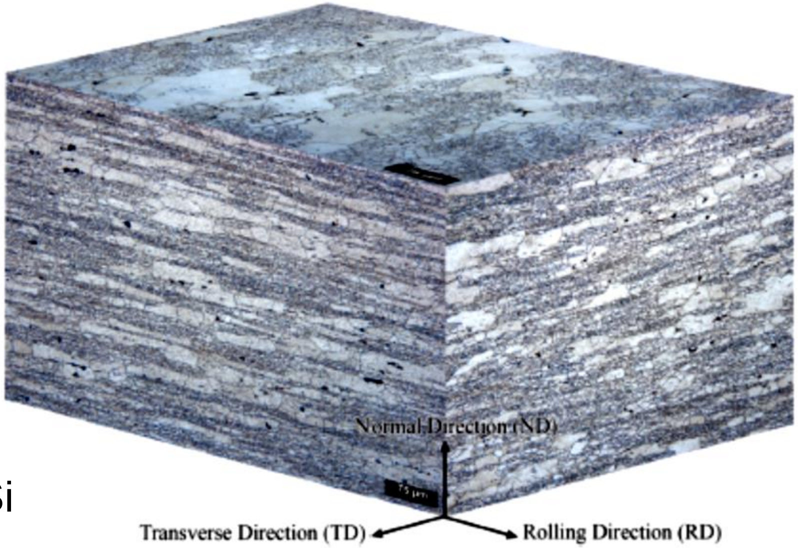
Previous work by our research group:

Starting material: AA7050-T7451 75mm thick plate.

Chemical composition (wt%):

5.58 Zn / 2.0 Cu / 1.88 Mg / 0.15 Zr / 0.07 Fe / 0.02 Si

T6I4 treatment parameters: 145°C/30min + 65°C/24h



A.L.M. Carvalho et al, 2022

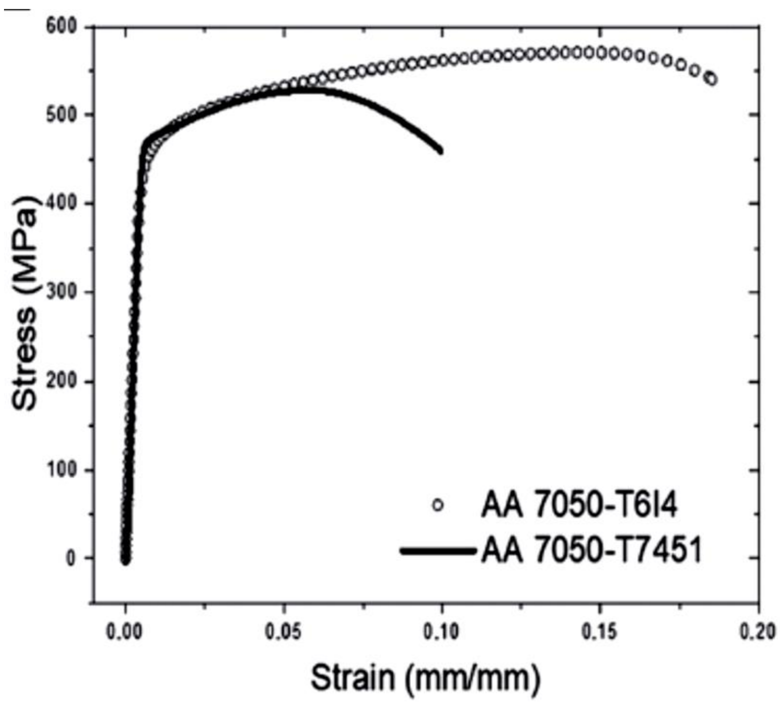
INTRODUCTION

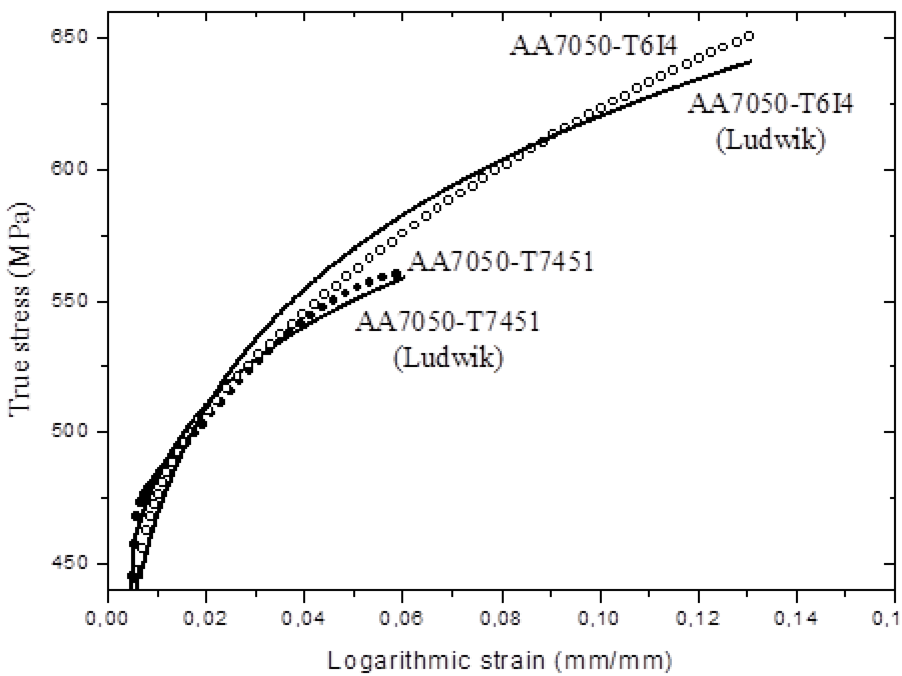
Previous work by our research group

A.M.B.S. Antunes et al, 2019

Tensile properties and hardness of AA7050 temper conditions.

Temper	σ_{YS} (MPa)	σ_{UTS} (MPa)	ε (%)	RA (%)	K (MPa)	n	HV
T7451	470.0	531.1	10.8	21.9	710.7	0.0837	170
T6I4	472.8	561.0	19.4	36.8	808.5	0.1216	171

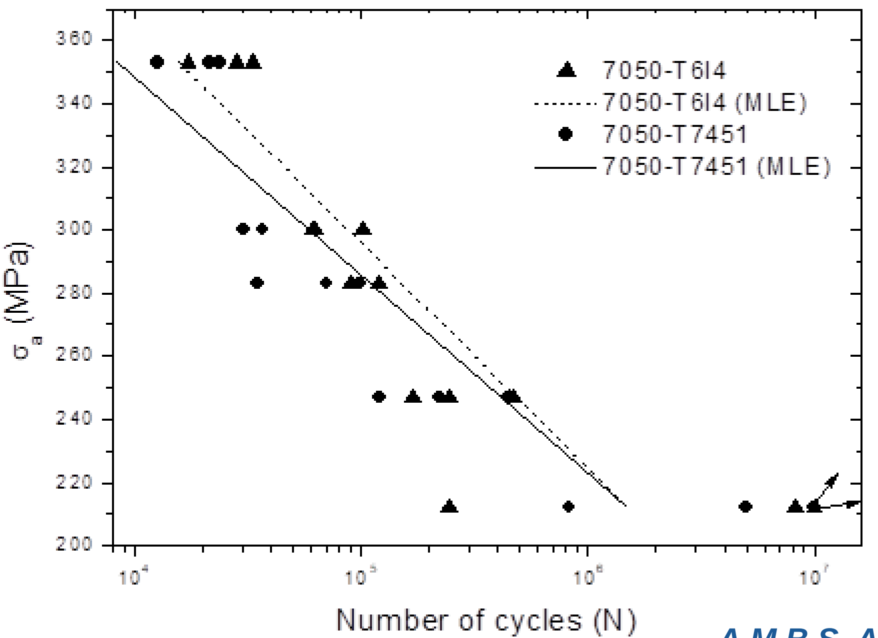


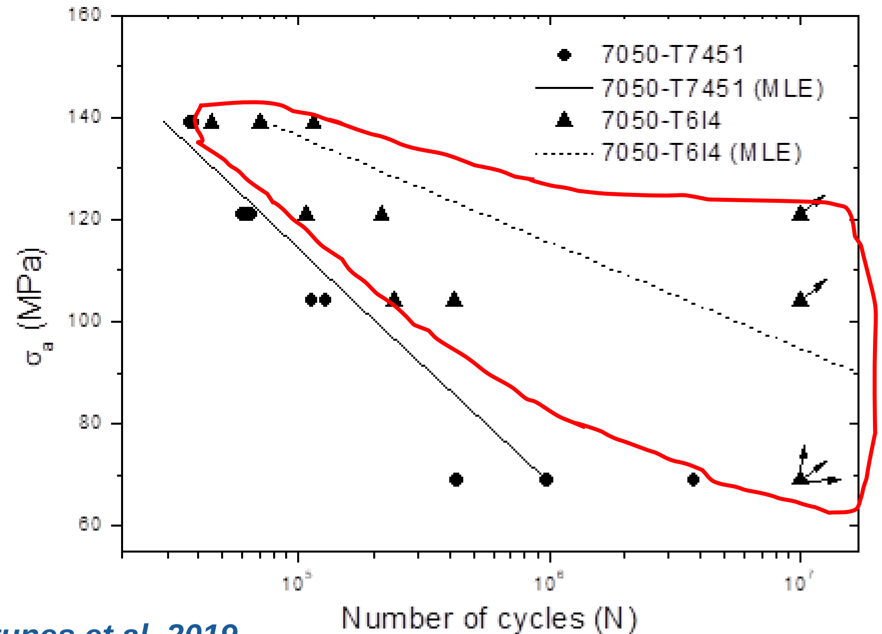


INTRODUCTION

Previous work by our research group

- Rotary bending fatigue tests
- Smooth and notched specimens





A.M.B.S. Antunes et al, 2019

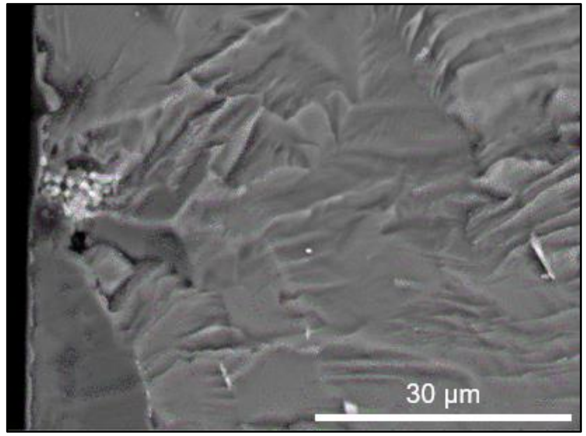
Notch sensitivity (q) and fatigue stress concentration factor (K_f).

AA7050-T7451			AA7050-T6I4		
N	K_f	q	N	K_f	q
10^5	2.52	0.71	10^5	2.14	0.53
10^6	3.21	1.03	10^6	1.03	0.47

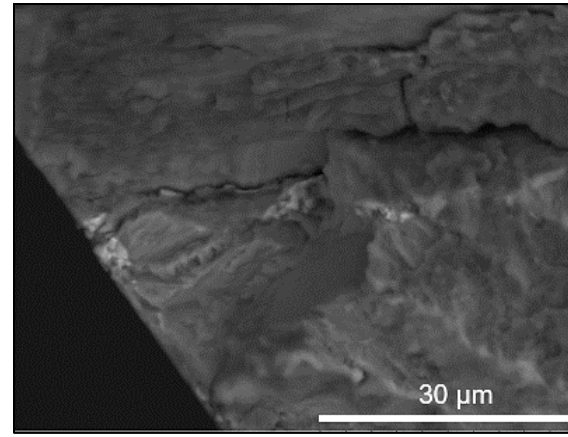
INTRODUCTION

Previous work by our research group

- Crack initiation sites: mainly Fe-rich intermetallic particles

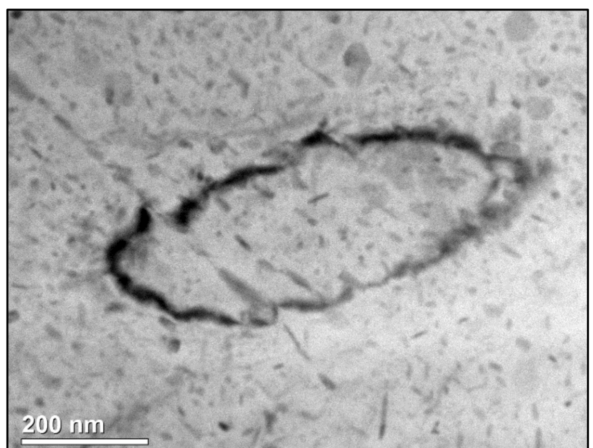


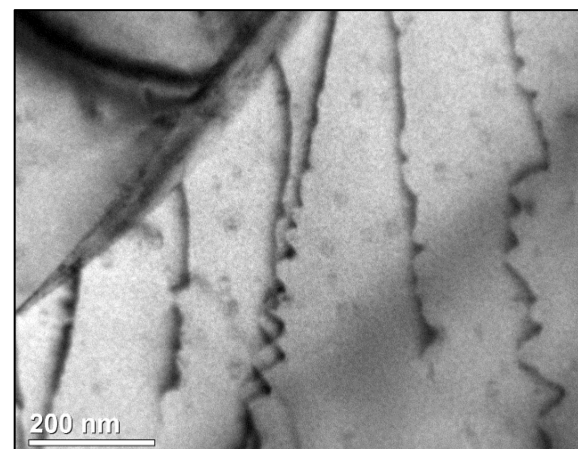
7050-T7451



7050-T6I4

- Pinned dislocations observed on fatigue tested specimens.





INTRODUCTION

The present work is aimed at evaluating the effects of the T6I4 treatment, with the same parameters adopted in the referred previous work, on the fracture toughness and fatigue crack growth behavior of AA7050 plate samples.

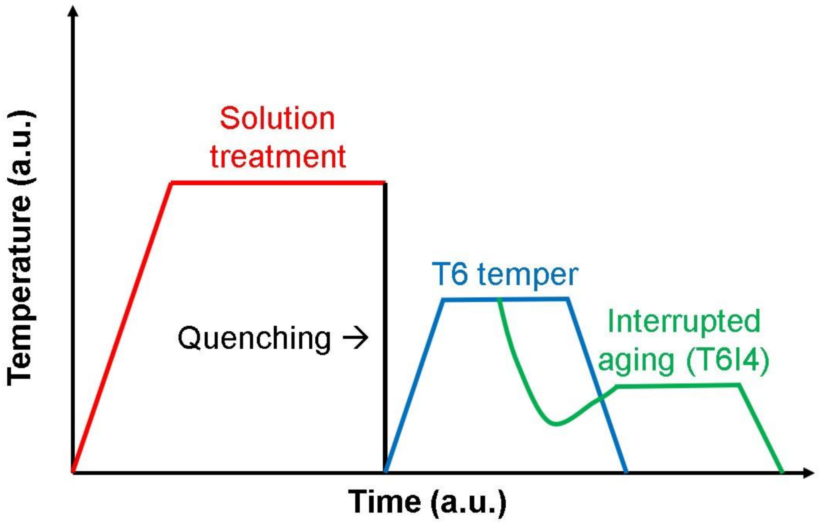
The fracture toughness of the material in both T7451 and T6I4 conditions is tentatively determined using the Chevron notch methodology and additional Charpy v-notch impact tests.

The fatigue crack growth tests were conducted under constant and variable amplitude loadings. In the former case, C(T) specimens were employed and the crack length was measured by the compliance method. In the latter case, hourglass shaped specimens were submitted to FALSTAFF spectrum loading with added marker blocks and the crack length was determined by quantitative fractography following methods described in literature.

MATERIAL AND METHODS

As-received material: 7050-T7451 alloy, same batch tested in previous work.

Heat-treatment: T6I4-65 secondary aging.



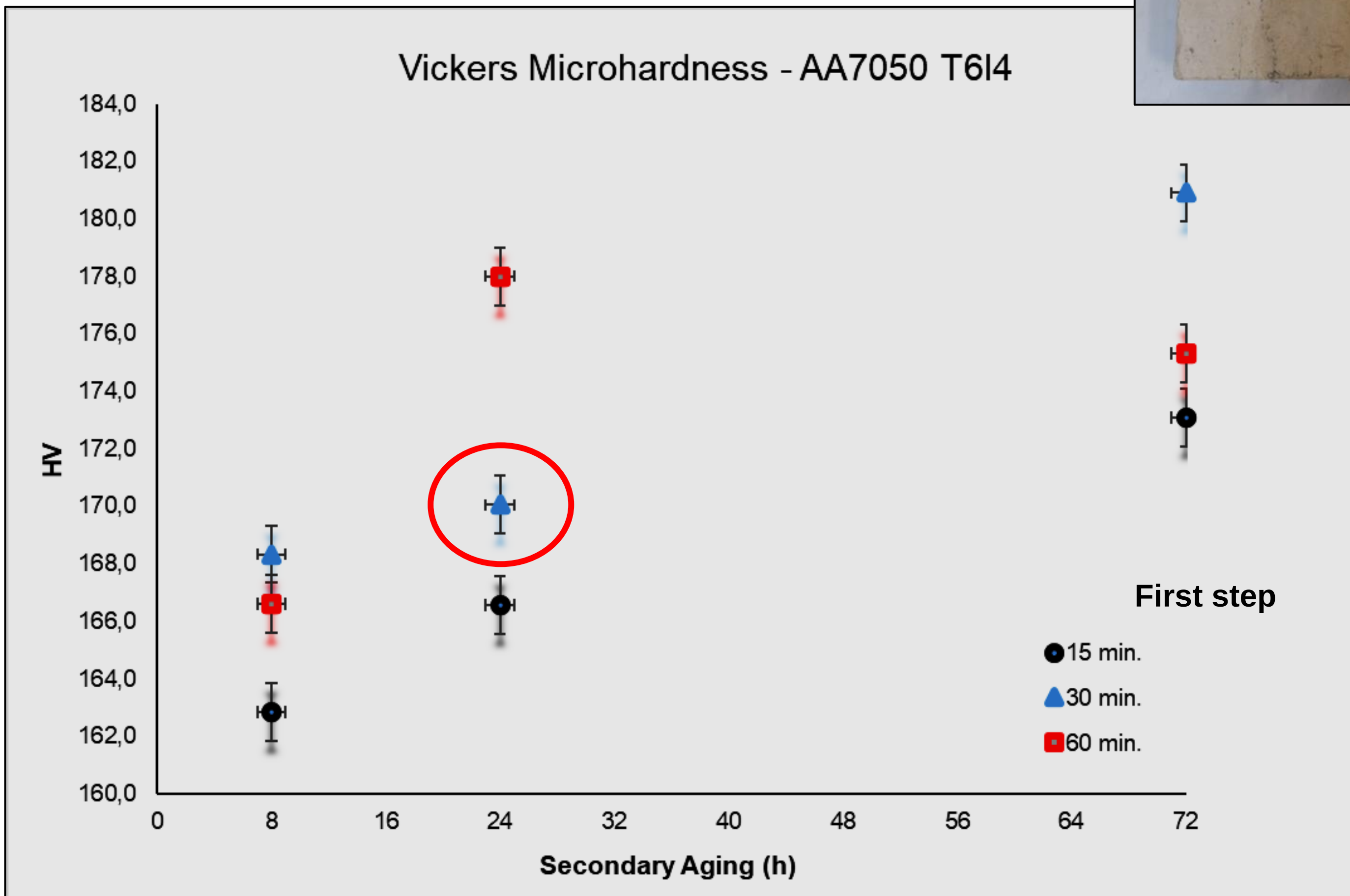
Muffle Furnaces room at EEL-USP

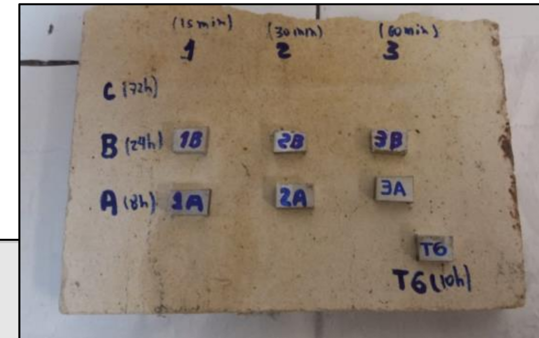
Heat treatment	Solution	Aging First step	Aging Second step
T6I4	485ºC - 3 h	145°C - 30 min	65°C - 24 h

Concurrent investigation on the Hardness values resulting from the variation of the aging stages duration:
1st step – 15, 30, 60 min
2nd step – 8, 24, 72 h

MATERIAL AND METHODS

Hardnening behavior

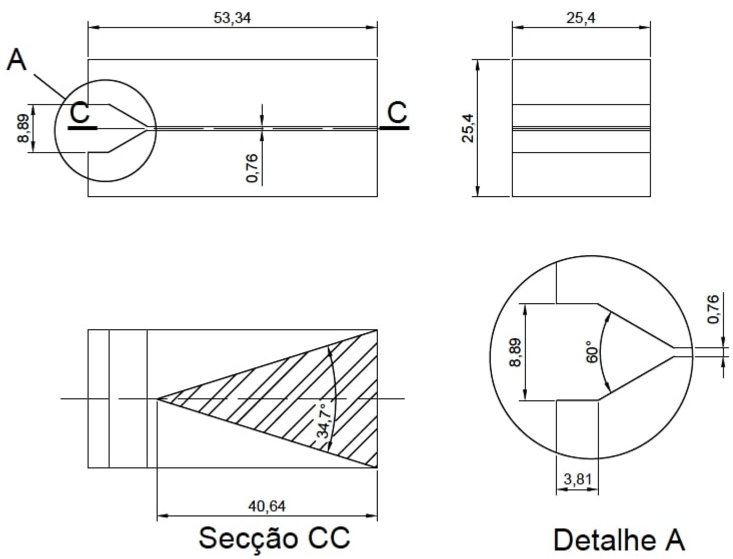




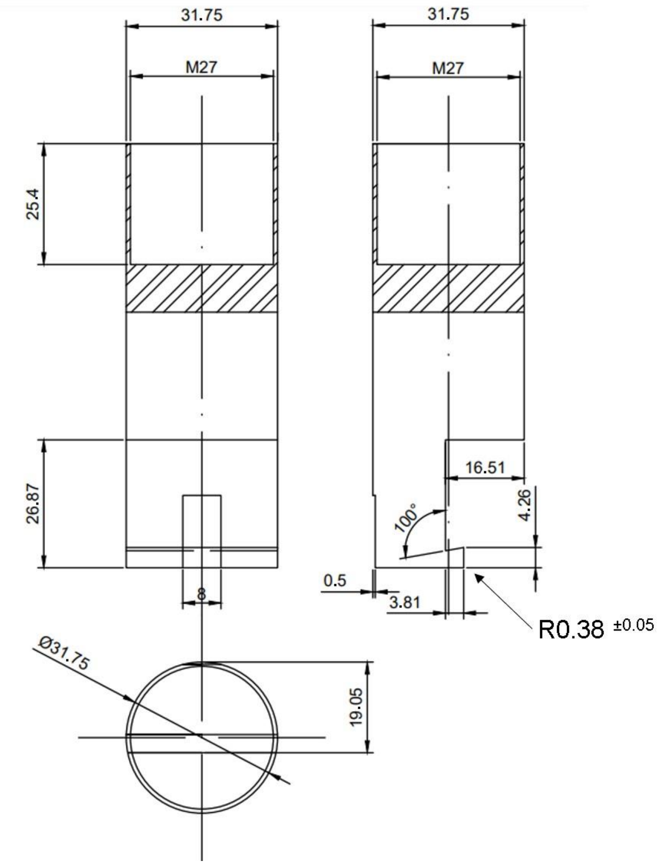
MATERIAL AND METHODS

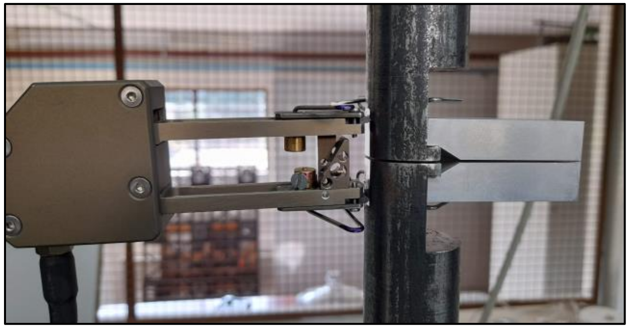
Fracture toughness

- Chevron-notched bar specimens, *W/H* = 3.8
- SAE 4340 steel grips, design from ASTM E1304
- EMIC/INSTRON machine, 25 mm extensometer
- Monotonic loading, displacement rate 0.2 mm/min
- Maximum force according to ASTM E1304, Annex A1



$$K_{QvM} = \frac{Y^* P_M}{B\sqrt{W}}$$





- Additional charpy v-notch impact tests also performed

MATERIAL AND METHODS

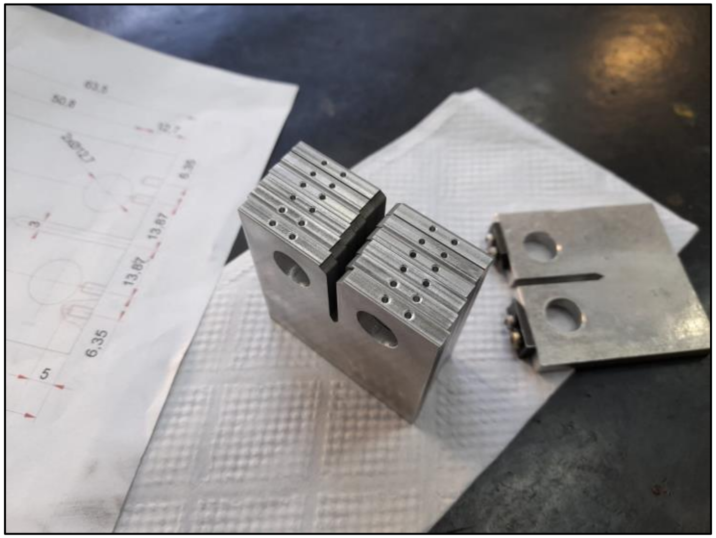
Chevron-notch fracture toughness test

Charpy v-notch impact test

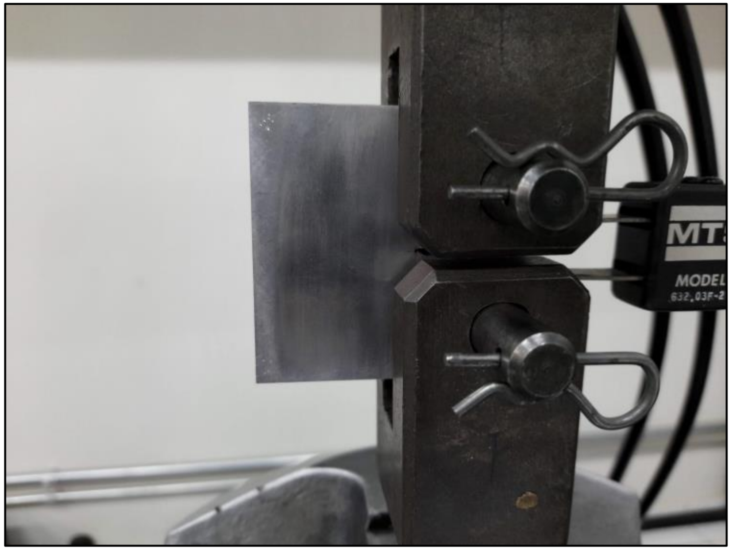
MATERIAL AND METHODS

Constant amplitude fatigue crack growth

- W50 C(T) specimens with thickness 4.5 mm
- MTS 810 machine, clip gage for indirect crack length measurement
- Sinusoidal waveshape, 5 Hz, R = 0.1
- Secant method for crack growth rate calculation
- ΔK calulation according to ASTM E647-15e1 Standard



Compact tension specimens

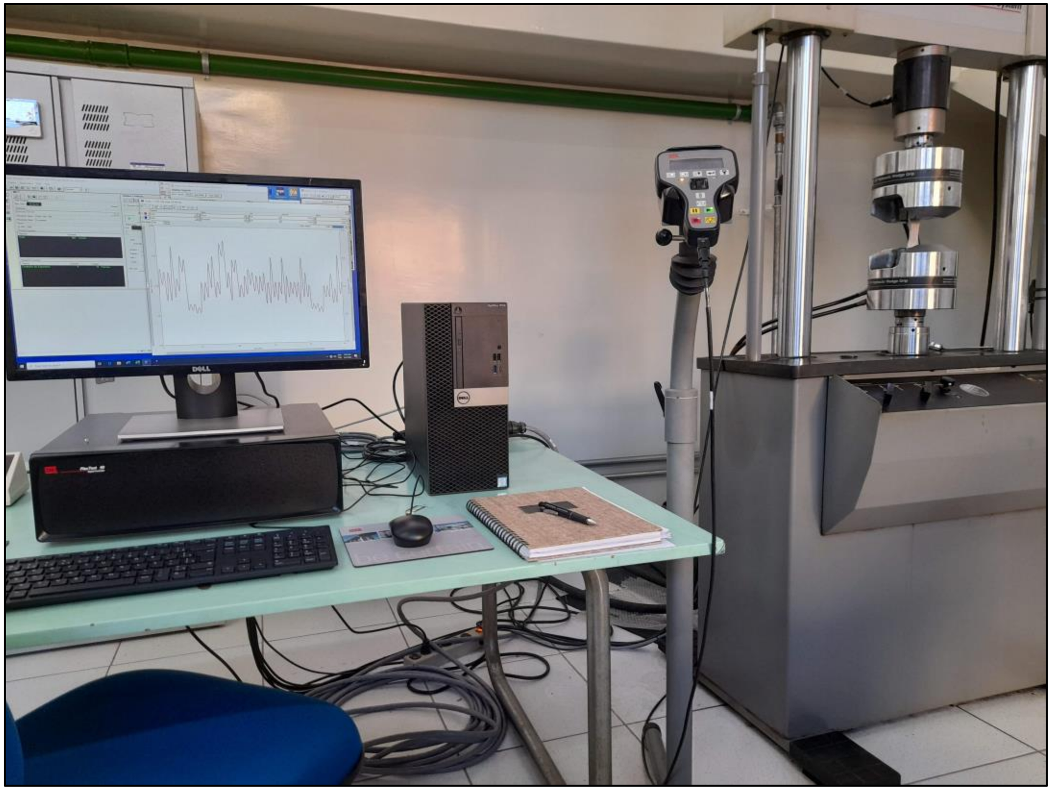


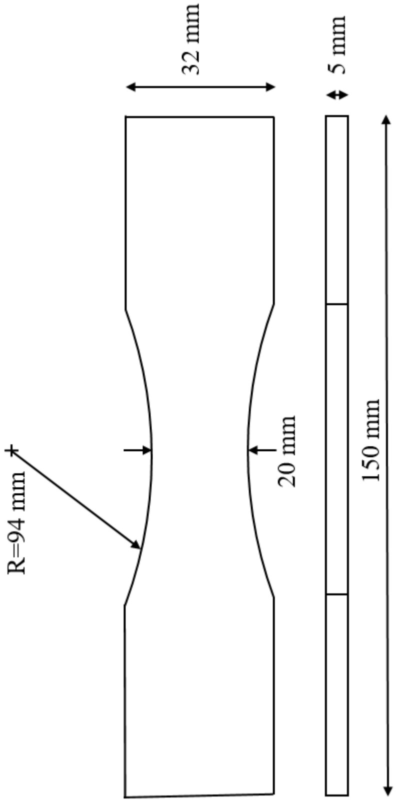
Loading device

MATERIAL AND METHODS

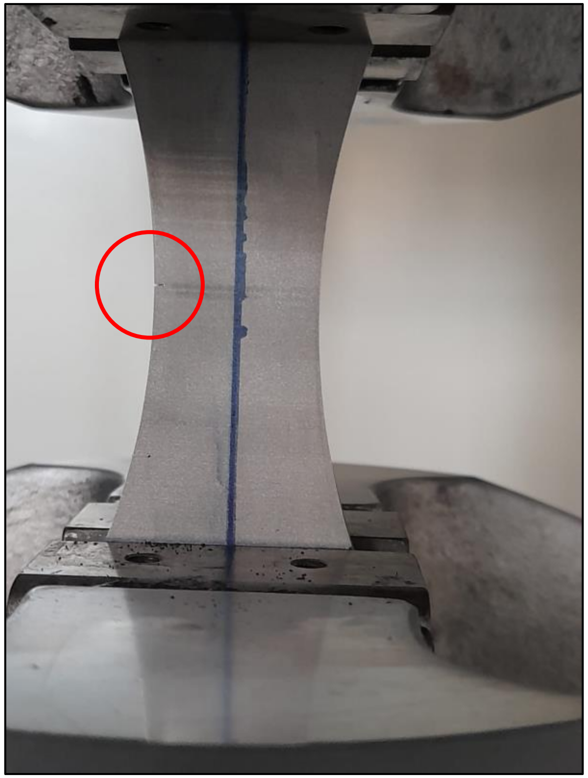
Variable amplitude fatigue test

- Hourglass shaped coupons, 5.0 mm thickness
- Force controlled cyclic loading based on FALSTAFF spectrum with added marker blocks
- Frequency 5 Hz; Peak stress levels 270 MPa (T7451) and 330 MPa (T7451 and T6I4)

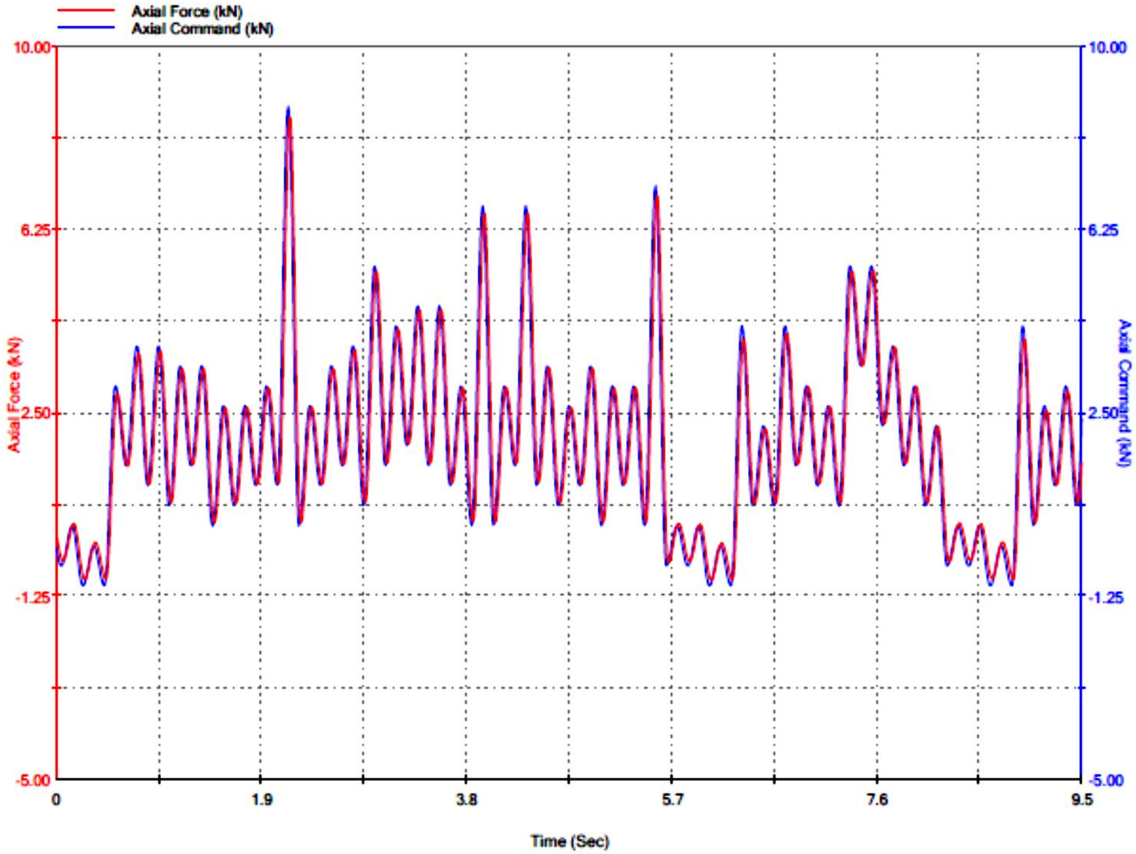




MATERIAL AND METHODS



Specimen with corner notch

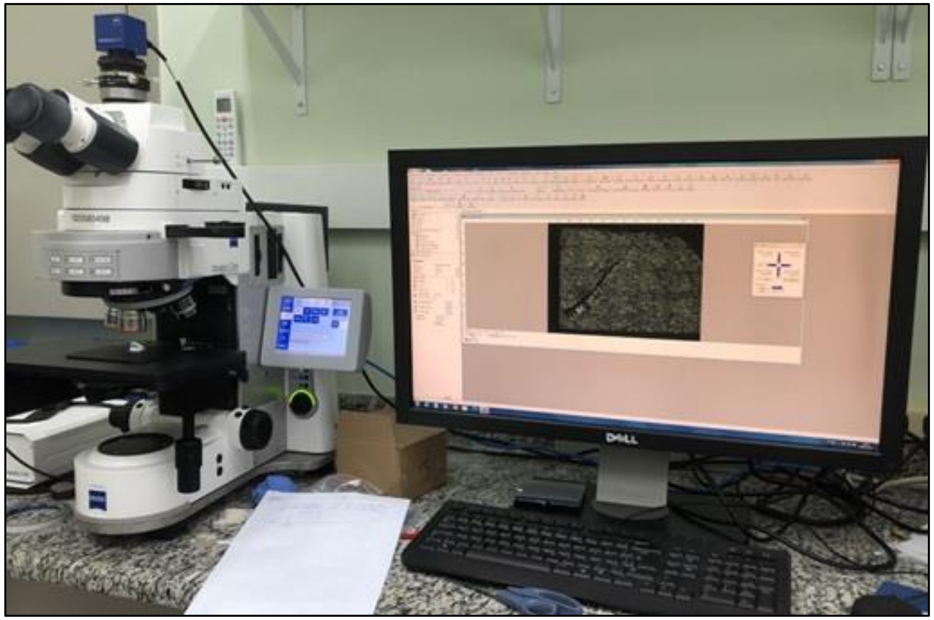


Example part of a loading spectrum

MATERIAL AND METHODS

Fractographic analysis

- Quantitative Fractography measurements in order to determine the crack growth data
- Zeiss AxioImager Z2m motorized upright light microscope
- Scanning Electron Microscope Tescan Mira 4
- Marker blocks and QF based on the works by: B. Dixon & S. Barter (2008); S. Barter & R.J.H. Wanhill (2009); L. Molent, Q. Sun and A.J. Grenn (2006), among others.



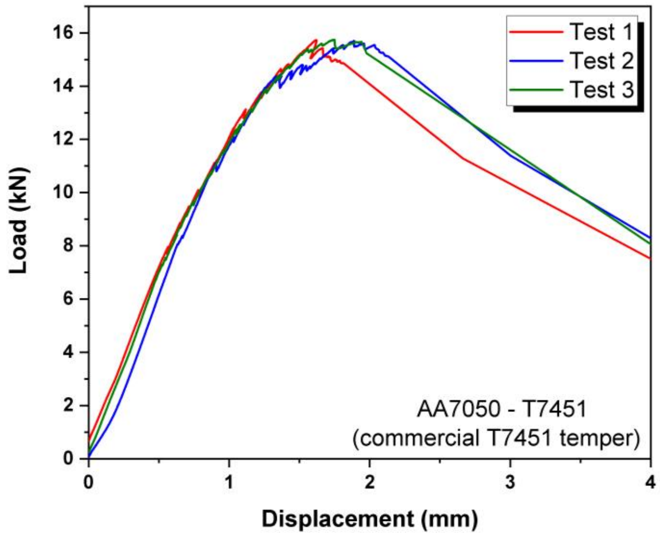
Zeiss Z2m motorized optical microscope

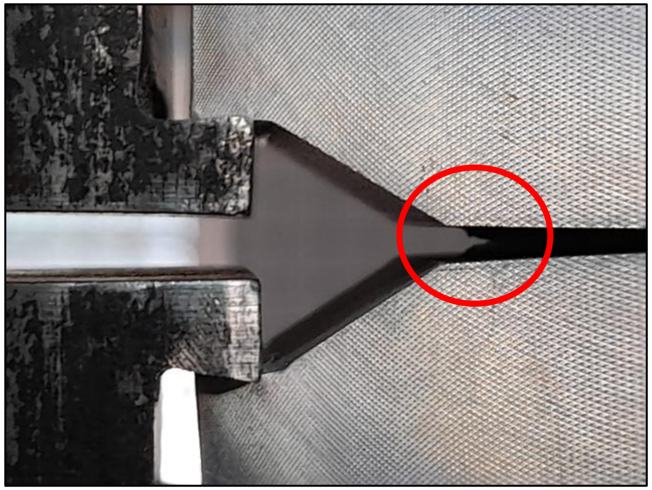
FESEM Tescan Mira 4

RESULTS AND DISCUSSION

Fracture toughness

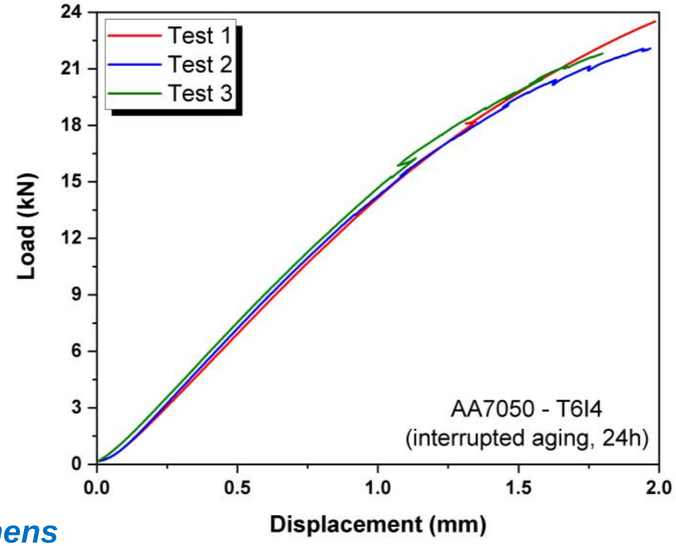
- Both material conditions presented slow propagating crack, sporadic audible noise (pop-in).
- Force growth at higher rate in T6I4 specimens.
- Total crack growth 5-6 mm from the tip of chevron ligament, followed by crack deviation.
- K_{Qvm} cannot be considered valid K_{Ivm} yet can be used to material comparison.
- Impact test: unbroken T6I4 specimens.





Chevron specimen with initiated crack

Fractured Charpy specimens



RESULTS AND DISCUSSION

Chevron-notch fracture toughness test results.

AA7050	*T7451*		*T6I4*	
Test number	P_M (kN)	K_{QvM} (MPa·m$^{0.5}$)	P_M (kN)	K_{QvM} (MPa·m$^{0.5}$)
1	15.73	39.6	23.54	63.1
2	15.70	41.0	22.08	56.7
3	14.34	37.3	21.86	55.3
Sample mean	15.26	39.3	22.49	58.4

Charpy V-notch impact test results.

AA7050	*T7451*	*T6I4*
Test number	*CIE* (J)	*CIE* (J)
1	7.36	21.44*
2	8.80	20.16
3	8.32	18.08
Sample mean	8.16	19.89

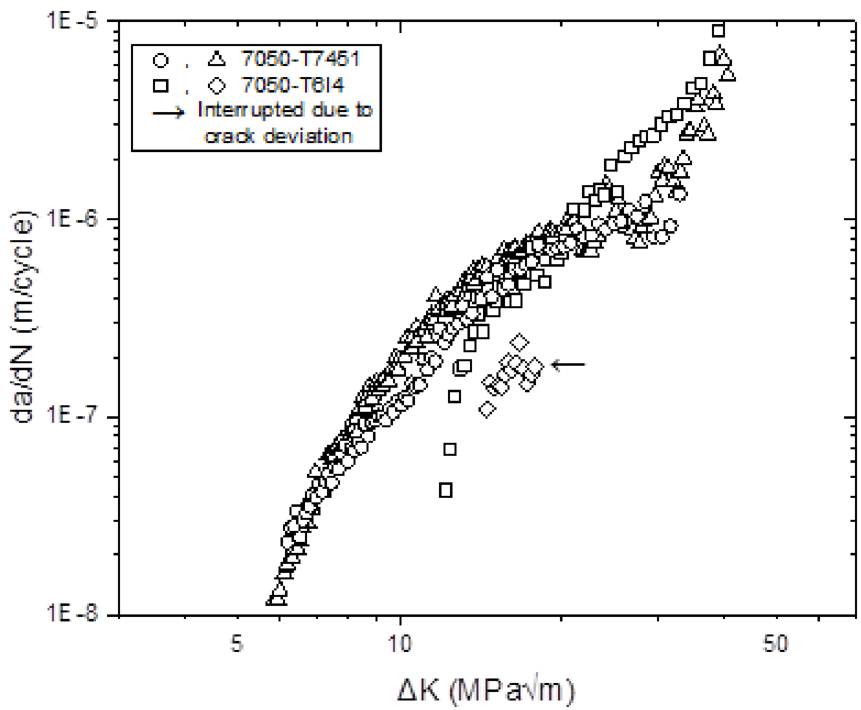
Fracture toughness estimation.

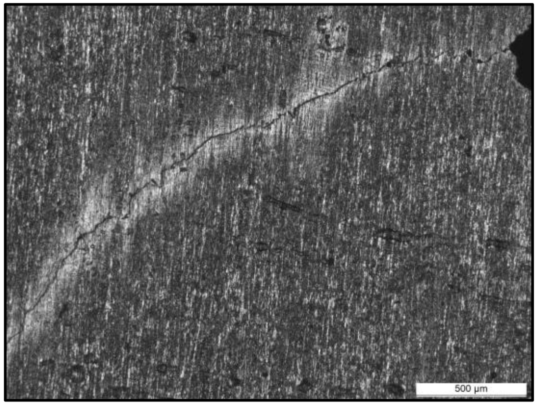
Author	*T7451*	*T6I4*
	Kc (MPa·m$^{0.5}$)	*Kc* (MPa·m$^{0.5}$)
Rolfe-Novak-Barson	32.3	67.7
Lucan et al.	21.3	35.2

RESULTS AND DISCUSSION

Constant amplitude fatigue crack growth

- Pre-cracking of T6I4 specimens lasted longer than T7451 ones.
- Crack arrest during pre-crack and crack deviation were also observed.
- Higher P_{max} was then adopted for T6I4 specimens.

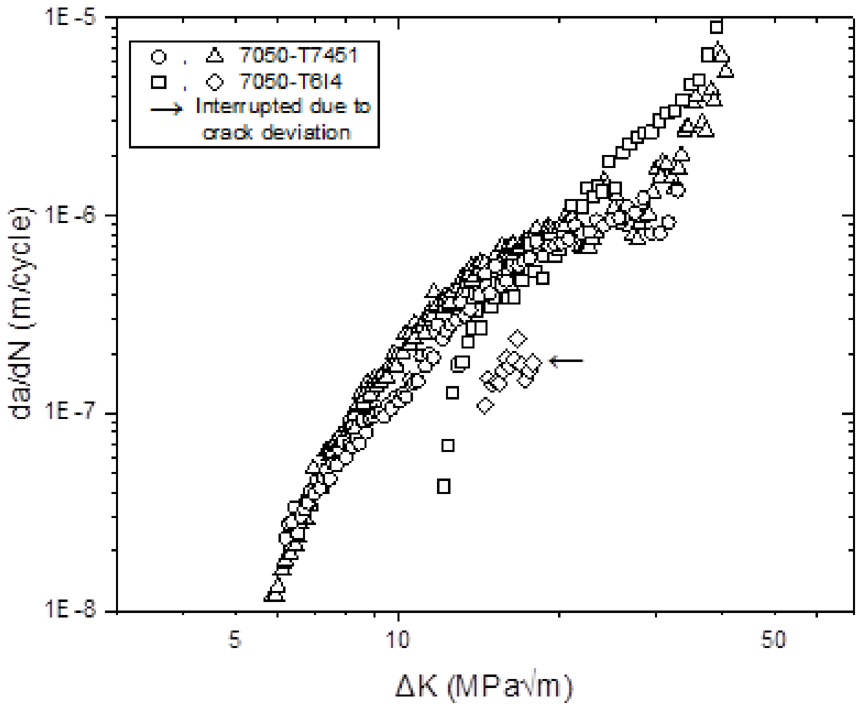


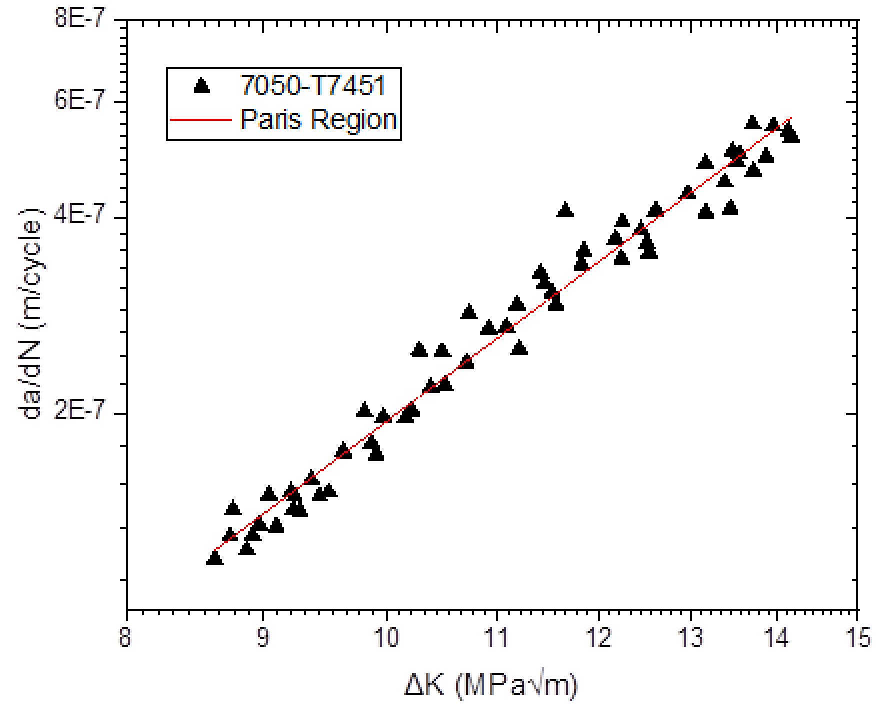


Crack deviation in T6I4 specimen

T7451 and T6I4 fatigue tested C(T) specimens

RESULTS AND DISCUSSION





- Least square fit for Paris equation:

$$\frac{da}{dN} = C(\Delta K)^n$$

Fitting parameters for the Paris model.

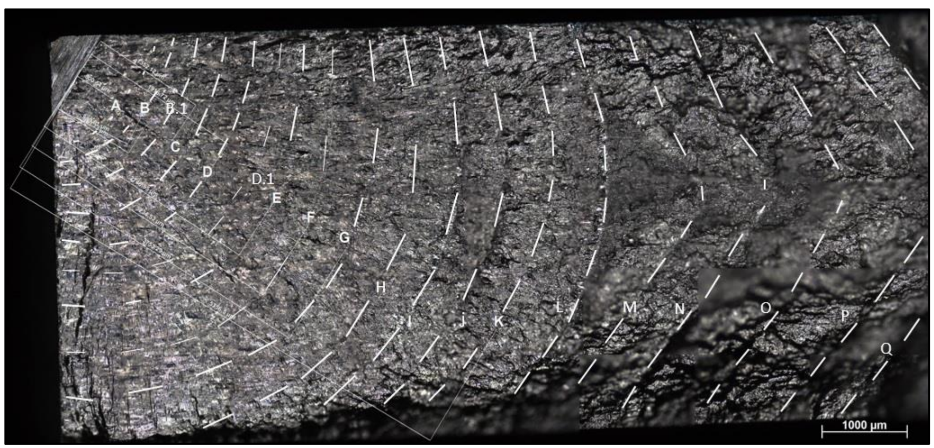
Specimen	*C*	*n*	*Correlation Coefficient*
T7451-a	1.578×10^{-10}	3.089	0.974
T7451-b	1.004×10^{-10}	3.097	0.962
T6I4	4.510×10^{-11}	3.268	0.893

RESULTS AND DISCUSSION

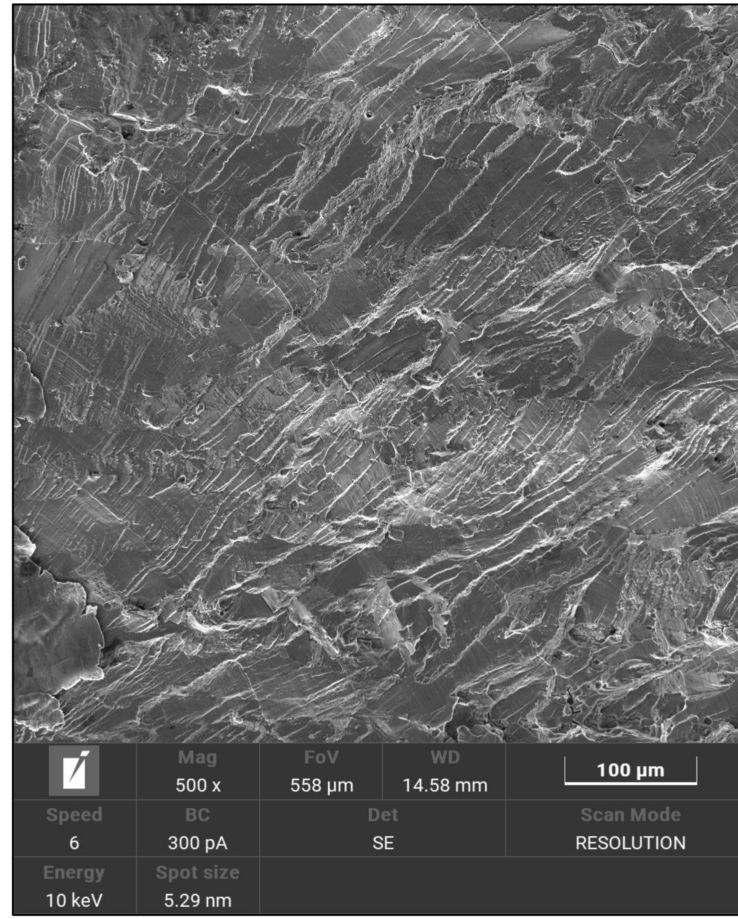
Spectrum loading tests

- Shape evolved from quarter-elliptical corner crack to edge crack with curved front
- Positions of the marker bands were measured

Spectrum loading fractured specimen (T6I4, 330 MPa)



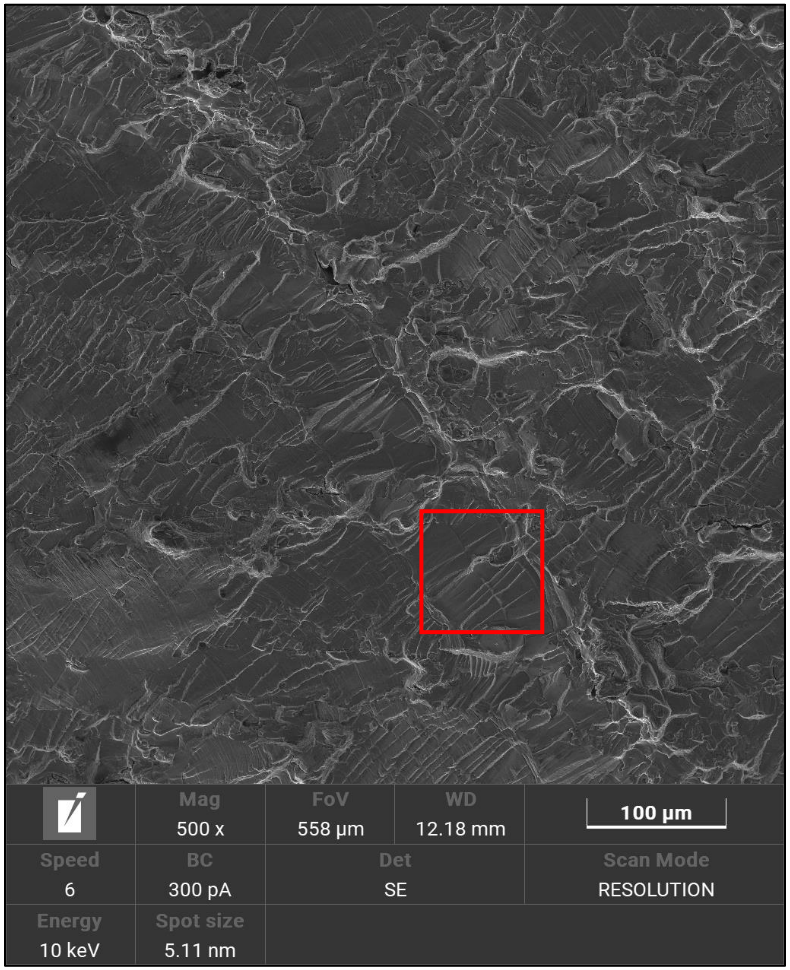
Fatigue crack growht map, optical micrograph (T7451, 270 MPa)

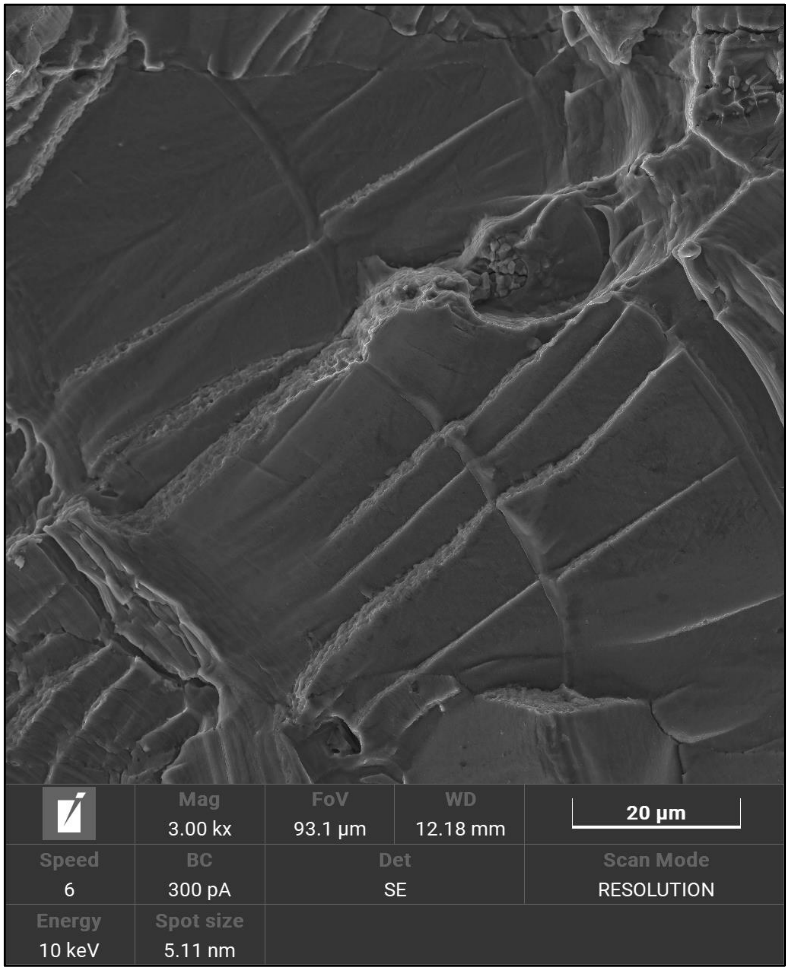


Fracture surface with marker band (T7451, 330 MPa)

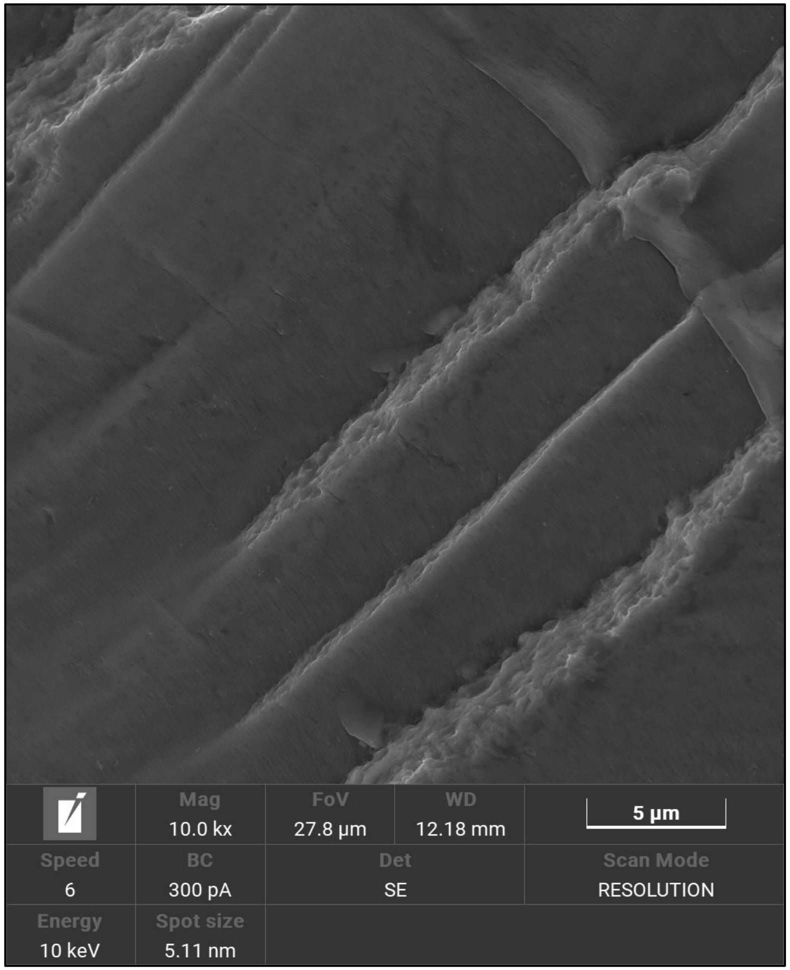
RESULTS AND DISCUSSION

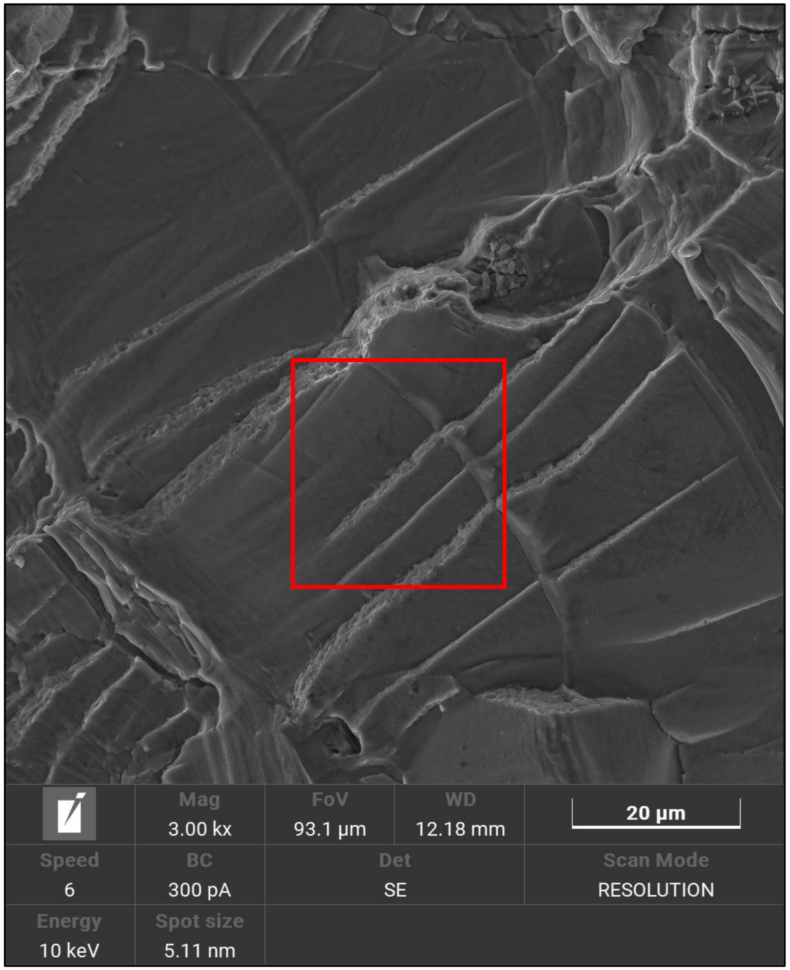
Marker band confirmation with SEM Images – T7451



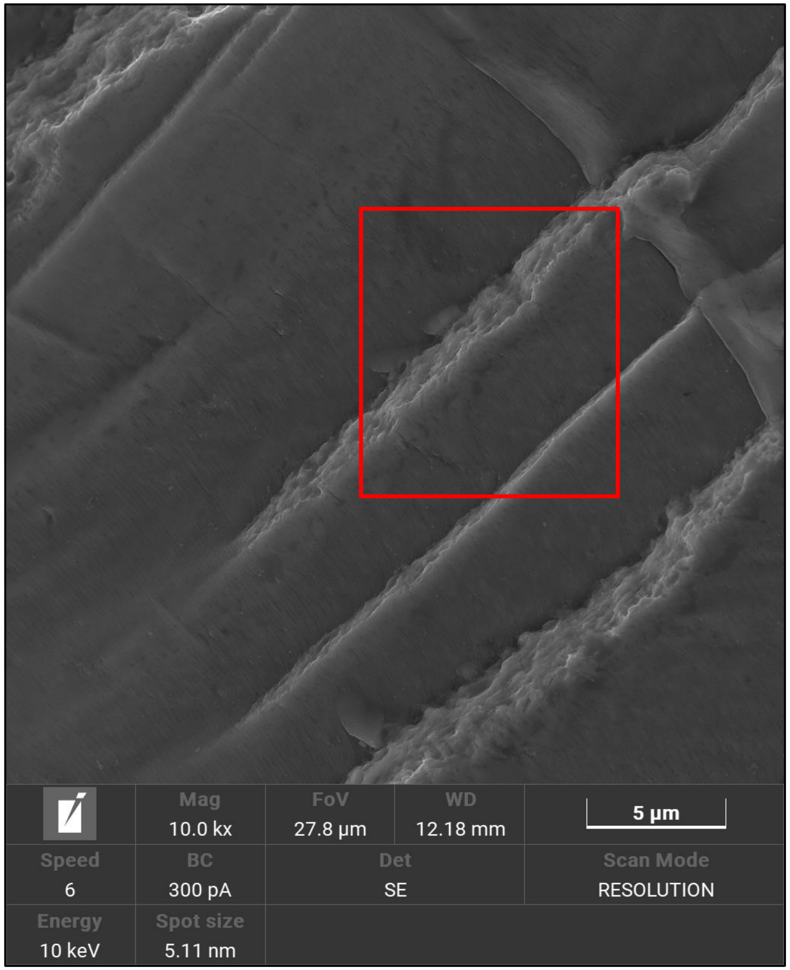


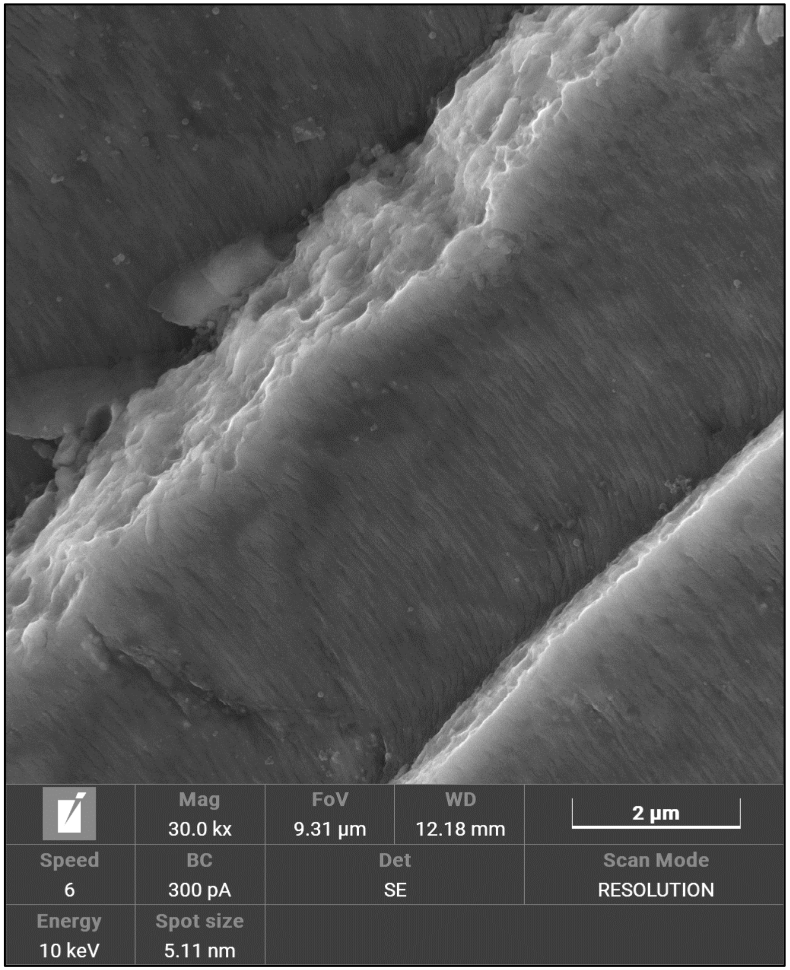
RESULTS AND DISCUSSION





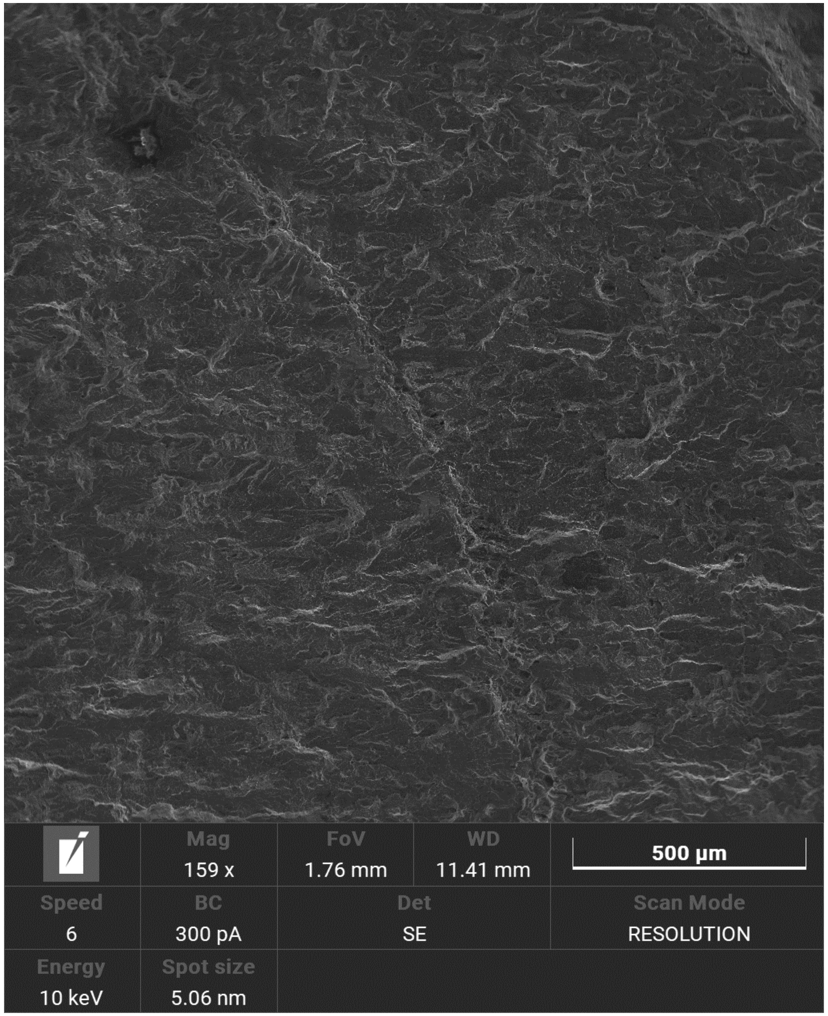
RESULTS AND DISCUSSION

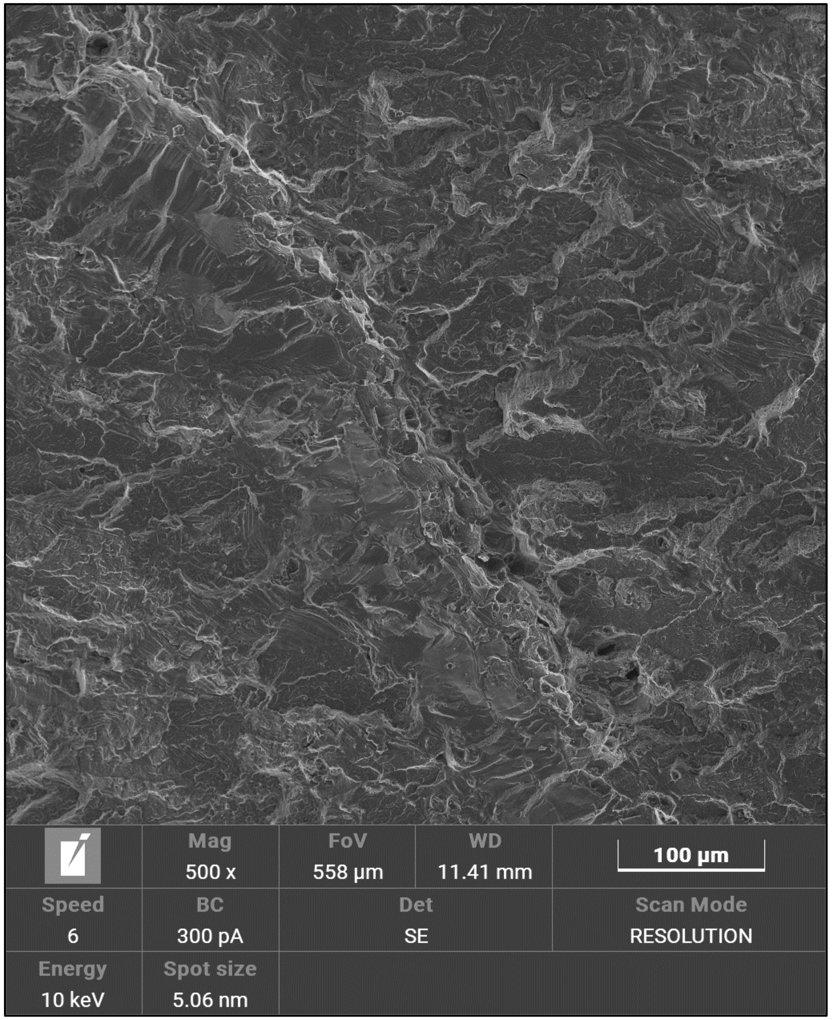




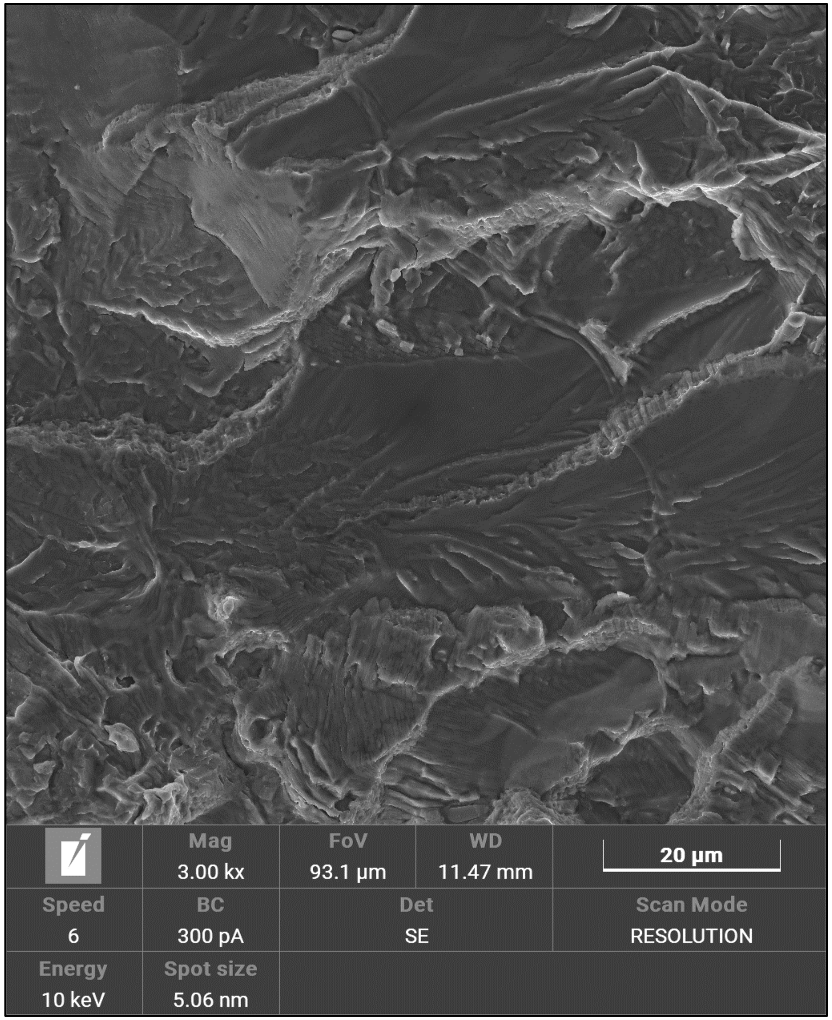
RESULTS AND DISCUSSION

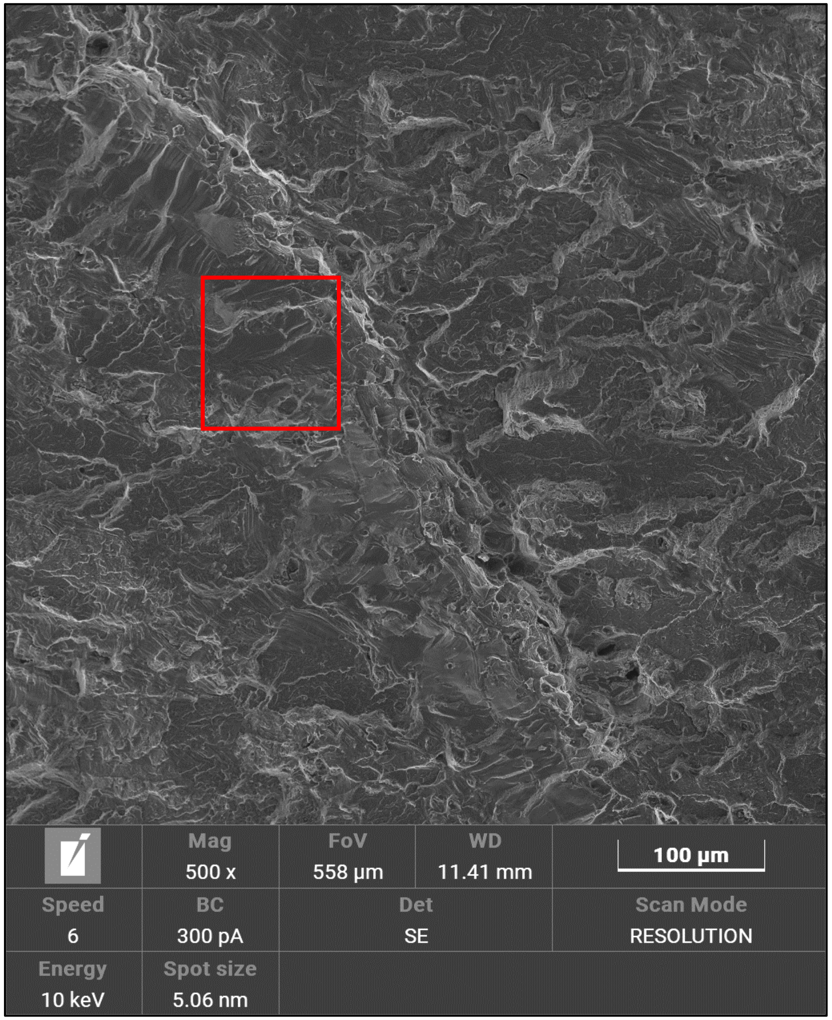
Marker band confirmation with SEM Images – T6I4



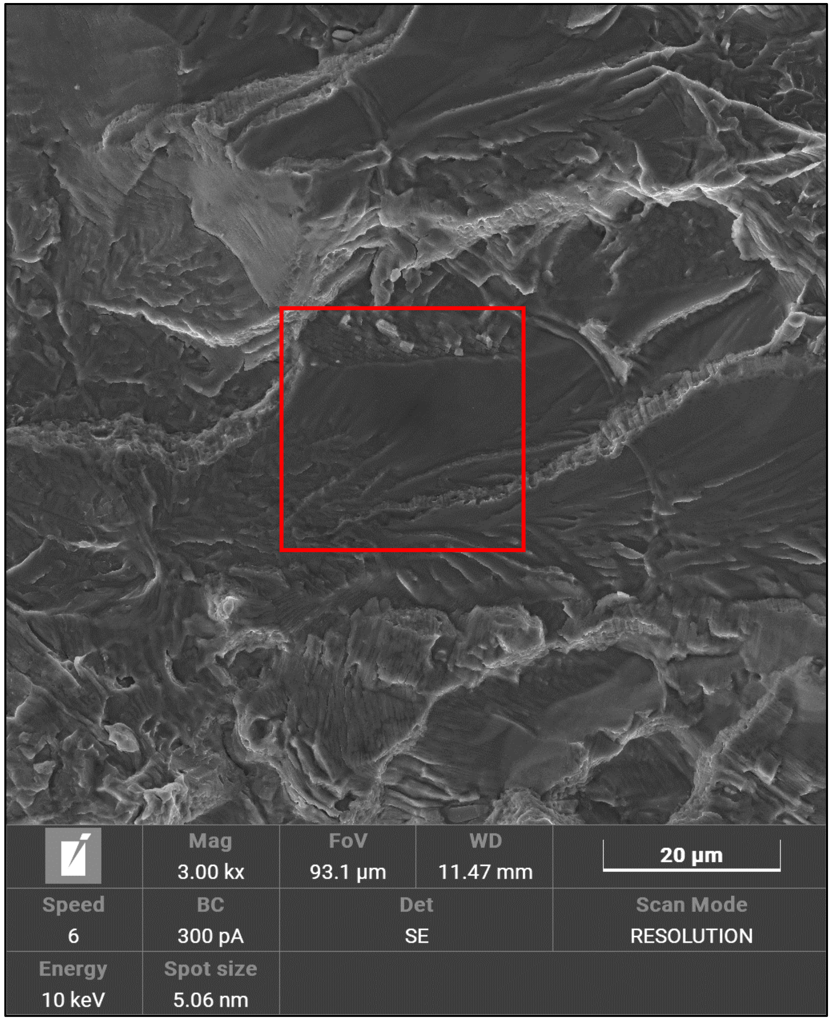


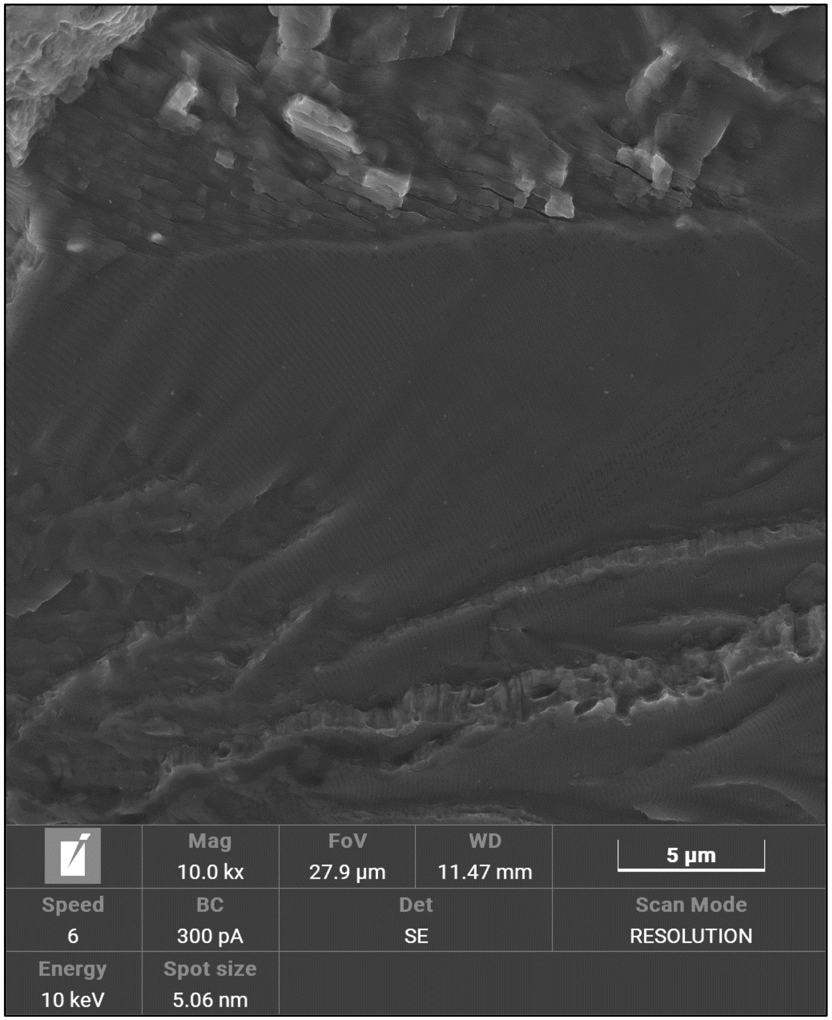
RESULTS AND DISCUSSION



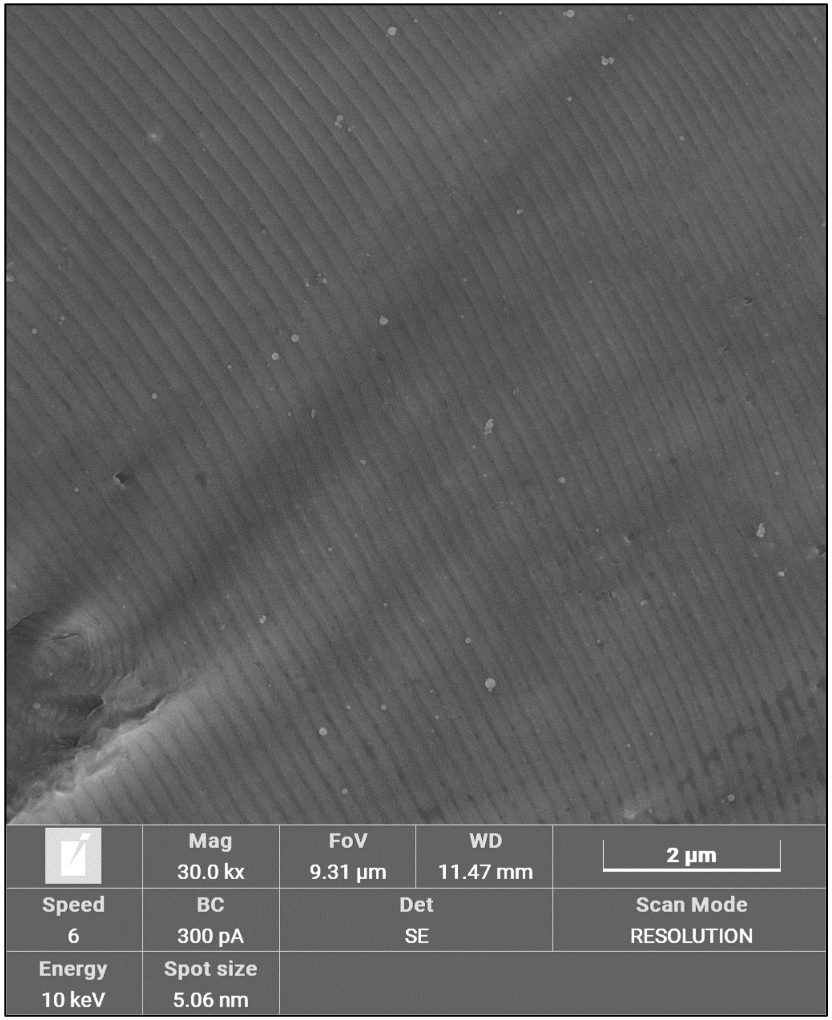


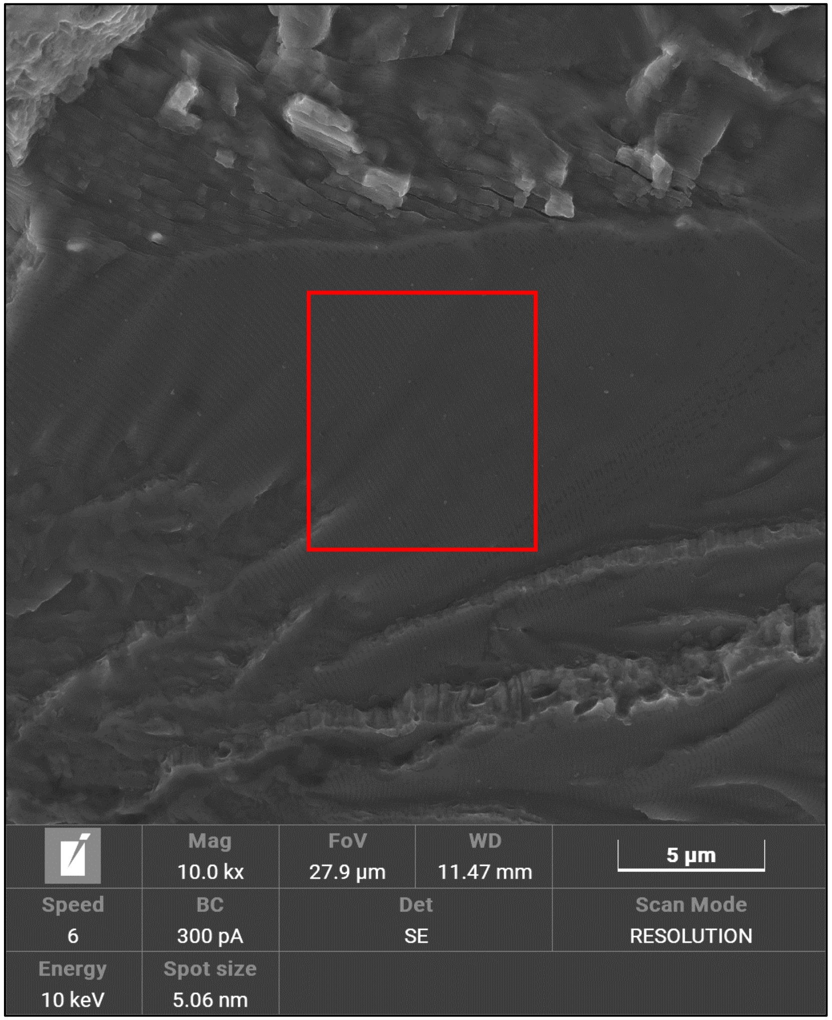
RESULTS AND DISCUSSION





RESULTS AND DISCUSSION

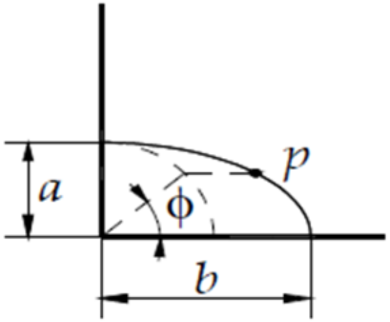




RESULTS AND DISCUSSION

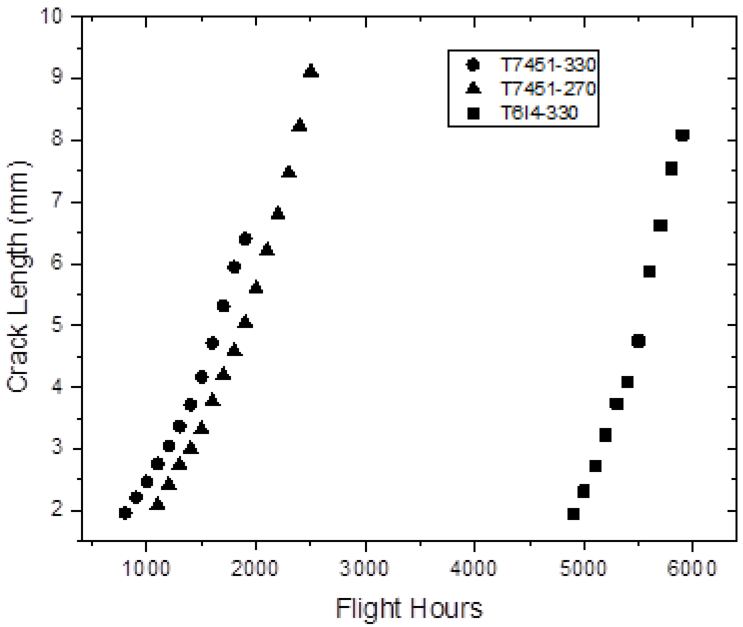
Spectrum loading tests

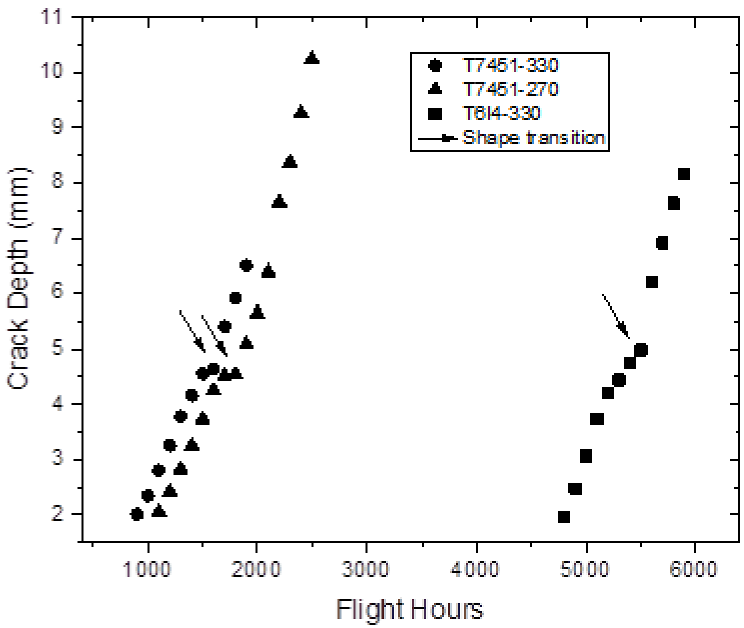
- Crack growth history was traced from the last visible marker band, which was assumed to be formed in last counted loading block.
- Each block spectrum of 9006 cycles represented 100 equivalente flight hours (Huang & Jones, 2017).
- Crack measurements taken on distinct positions of each marker band.



Spectrum blocks withstood by the specimens:

T7451-270 = 25   T7451-330 = 19   T7451-330 = 59

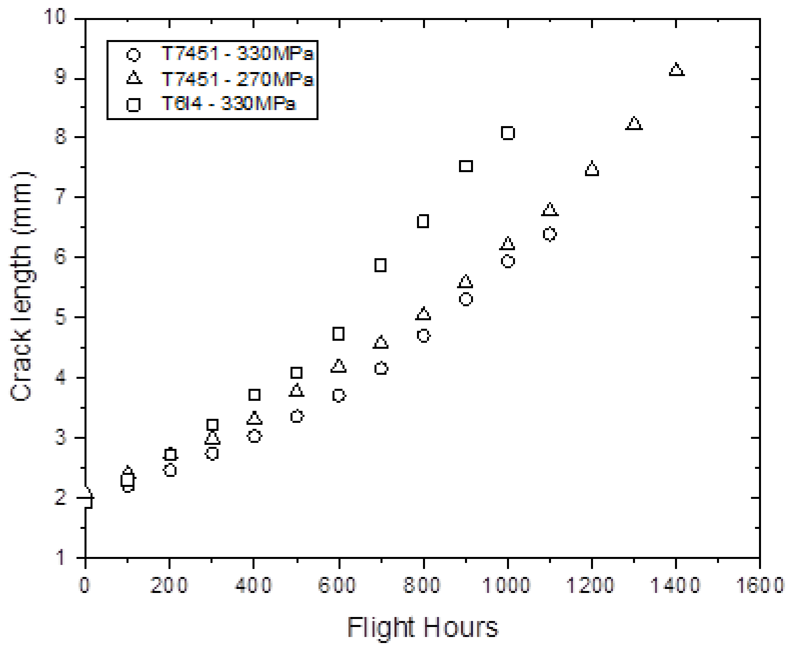


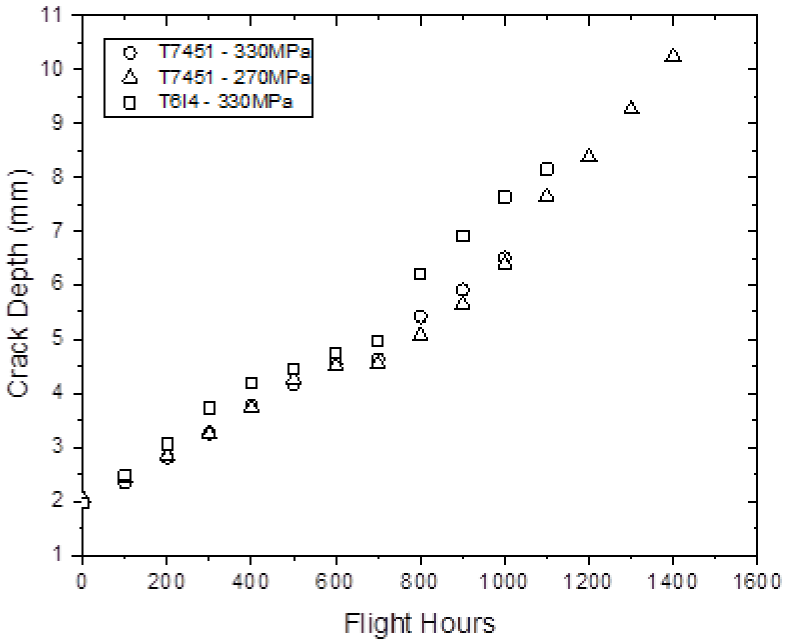


RESULTS AND DISCUSSION

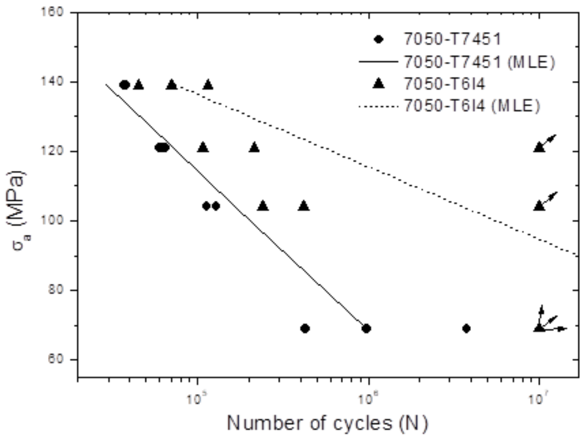
Spectrum loading tests

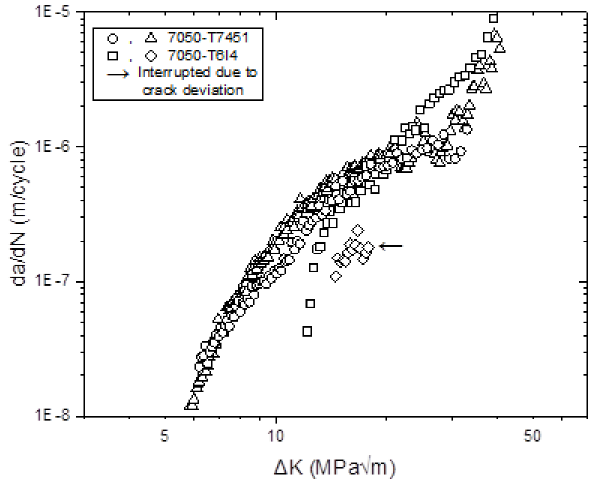
- Fatigue crack growth data translated to the same initial point
- Higher propagation life was observed for T7451 - 270 MPa specimen
- Life increase provided by T6I4 is not related to macrocrack propagation life

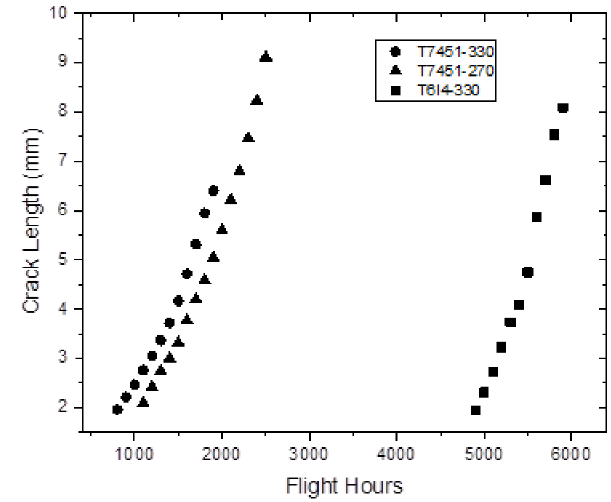




RESULTS AND DISCUSSION

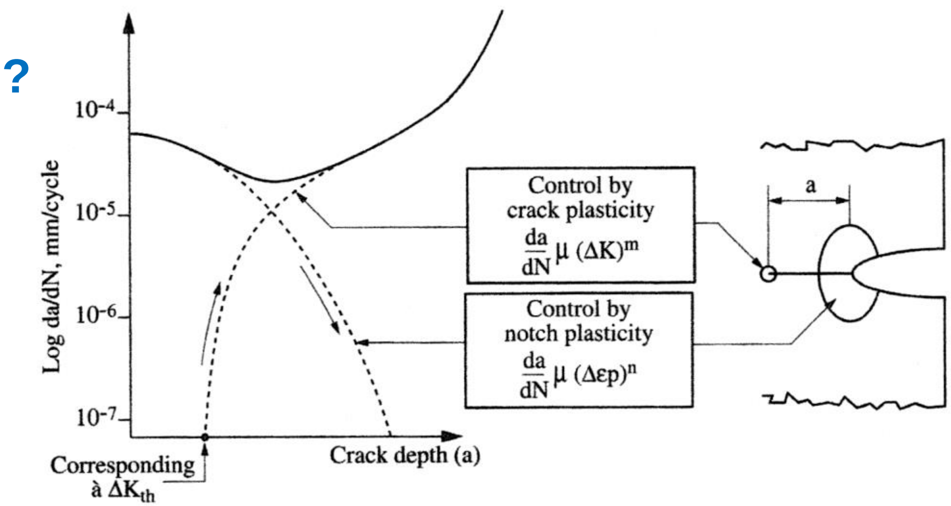






What do these results have in common?

- Transient notch effect: the growht of a short fatigue crack can be strongly affected by the plastic deformation at the notch root.
- Results indicate that T6I4 temper as adopted in this work is more prone than T7451 to this effect, which retards early crack growth.



Growth of a short crack affected by notch (Verreman, 2010)

CONCLUSION

This work presented results of chevron notch fracture toughness and fatigue crack propagation tests carried out on samples of AA7050 alloy with two temper conditions: T7451 and T6I4.

Fracture toughness tests: T6I4 specimens achieved higher loads as the crack nucleated and grew from the notch tip, resulting in higher K_{QvM} values (58.4 MPa·m$^{0.5}$) than T7451 ones (39.3 MPa·m$^{0.5}$). Complimentary Charpy v-notch tests also suggested higher fracture toughness for T6I4 by means of estimation formulas.

Higher fracture toughness did not mean higher fatigue crack growth resistance, as the crack growth behavior of these material conditions under both constant amplitude and spectrum loadings was found to be nearly similar.

On the other hand, the fatigue crack growth tests also lead us to conclude that T6I4 material condition is more prone to the transient notch effect that retards the initial growth of a nascent crack. This effect is not manifested for a large crack, when the plastic zone is small compared to the extent of the elastic stress field ahead of the crack tip and the stress intensity factor K is the sole driving force for crack growth.

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THANK YOU !