AFGROW Workshop 2016

AFGROW Release 5.3 Status

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LexTech, Inc .

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AFGROW.NET

Feature List for the release 5.3

- **64 bit version - 100%**
- **Converted AFGROW encoding from western Latin character set to Unicode 32 – 100%**
- **New spectrum format in AFGROW - 100%** (Currently, only the Axial component is used)
- **New weight functions solutions (crack at hole, stress distribution in the C-direction for part through cracks) -99%**
- **Using different material data as a function of spectrum data – 100%**
- **Applying different material data to different crack directions – 100%**
- ~~**Ability to Replicate Results From Previous Versions (back to Version 5.01)**~~
- **Option to Save Input File With Retardation State Data for Later Restart – 30%**

Bold – Work started
Red – High Priority
Blue - Finished

Feature List for the release 5.3

- **Adding an option to control the % of the axial load solution that is used to approximate the out-of-plane bending solution for straight through-the-thickness cracks.– 50%**
- **Corrosion – Exfoliation – 100%**
- **Corrosion – Intergranular – 100%**
- **Corrosion – Pitting – 80%**
- **Corrosion - Crevice – 60-80%**
- ~~Undo-Redo~~
- **New solution for a corner crack at the countersink knuckle – 50%**
- **Server based material database – requested by Gulfstream – 70%**
- **Convert material data from AFMAT to a useable format in AFGROW**
- **Bearing solution for corner crack(s) at a countersunk hole – 15%**
- **Bearing solution for the advanced through crack(s) at hole– 100%**
- AFGROW output post processing
- **New 2D table for residual stress data (similar to the 2-D user defined beta) 100%**

Bold – Work started
Red – High Priority
Blue - Finished

Feature List for the release 5.3

- Output intervals printed in "hours" if the option to display life in hours is selected in the Output Intervals tab, the crack length plots also should be converted to hours
- In the Propagation Limit tab, the option to stop at a cycle limit should be automatically switched to hours if the User has elected to display the life in hours.
- **Add the capability to use the current 2-D User-Defined Beta model for 2, inter-dependent through cracks that can be assigned different plate thickness values = 100%**
- **Add single edge crack model with the finite height – provided by SAFE, Inc - 100%**

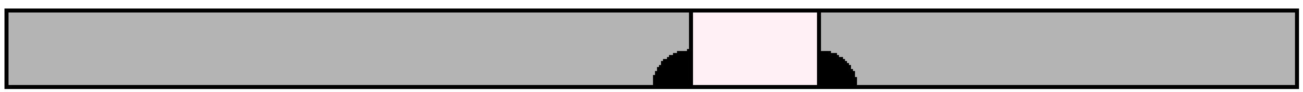
Bold – Work started
Red – High Priority
Blue - Finished

New weight functions solutions

- Added 3 new solutions
  - Corner cracks with stress distribution along the C direction
  - Single through edge crack with symmetry condition at the crack edge
  - Single through edge crack with symmetry condition at the edge away from the crack
- Status: Finished coding the solutions, coding verification is done, testing solutions accuracy and applicability, AFGROW GUI modified
- To do: finish testing the accuracy and applicability of the solutions

64 Bit AFGROW Performance Test

Advanced double cracked hole with offset



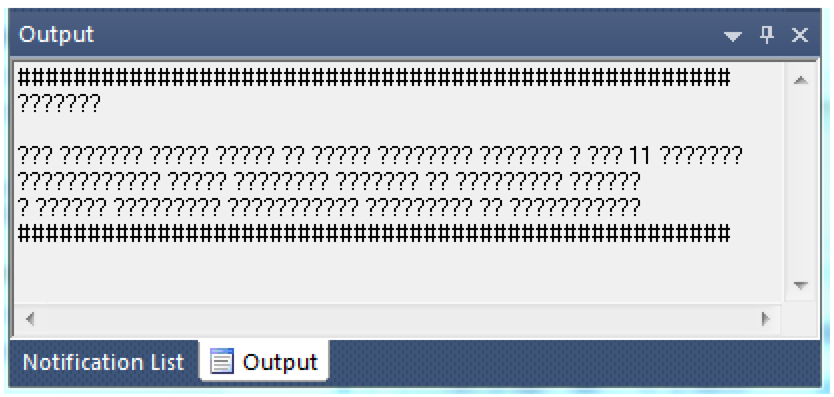
Model	Spectrum	Time 5.2 (sec)	Time 5.3 (sec)	Difference
Multipoint	FALSTAF	122	90	35.56%
Multipoint	Const Amplitude	8	6	33.33%
2 points	FALSTAF	73	62	17.74%
2 points	Const Amplitude	5	4	25.00%

32 to 64 bit upgrade was sponsored by APES

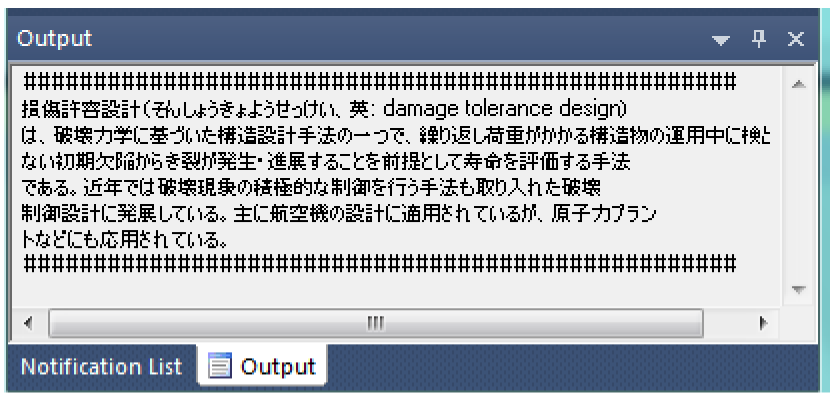
Unicode

- Provides ability to have localized strings in AFGROW, like comments, material names, etc.
- Supports localized file and folder names

5.02



5.03



New solution for a corner crack at the countersink knuckle

- Based on Jody Cronenberger master's thesis
- Tension loading only
- Solution Space:
  - D/T – 0.3 to 2.6;
  - CD (Countersunk Depth)/T - 0.001 to 0.99 (0.15),
  - C/T - 0.0125(D/T) +0.002 to 2.5(D/T)
  - A/C/T – 0.5 to 4
- Status: Finished coding the solution implementation
- To do: Understand the solution boundaries and do verification runs, add COM API support, finish GUI integration

Using different material data as a function of the spectrum

- Status: Finished the Spectrum Manager changes, finished AFGROW coding
- Material data will consist of different material “sets”
- One material “set” is always default
- Material sets can be tagged for different conditions
- Only the temperature “tag” can be used right now
- Applicable only for tabular lookup data, but code infrastructure has been changed to handle any AFGROW material model if necessary, and requires only GUI changes
- Requires a spectrum with temperature “tags” applied to the sub-spectra
- Must be used with the new XML spectrum format
- New XML tabular lookup data file format
- Ability to use old tabular lookup data files for either growth direction
- The resulting DAX input file is backward and upward compatible

Applying different material data to different crack directions

- Status: Finished AFGROW coding
- Works only with A and C directions (Ct and C direction use the same material data)
- Applicable only for tabular lookup data, but code infrastructure has been changed to handle any AFGROW material model if necessary, and requires only GUI changes
- C direction is always the default direction
- Will not work with the Advanced multipoint corner crack(s) at a hole model
- Can be used in conjunction with the "Using different material data as a function of spectrum" change
- DAX file is backward and upward compatible
- Plugin model needs to be changed to handle different material data to the different crack directions

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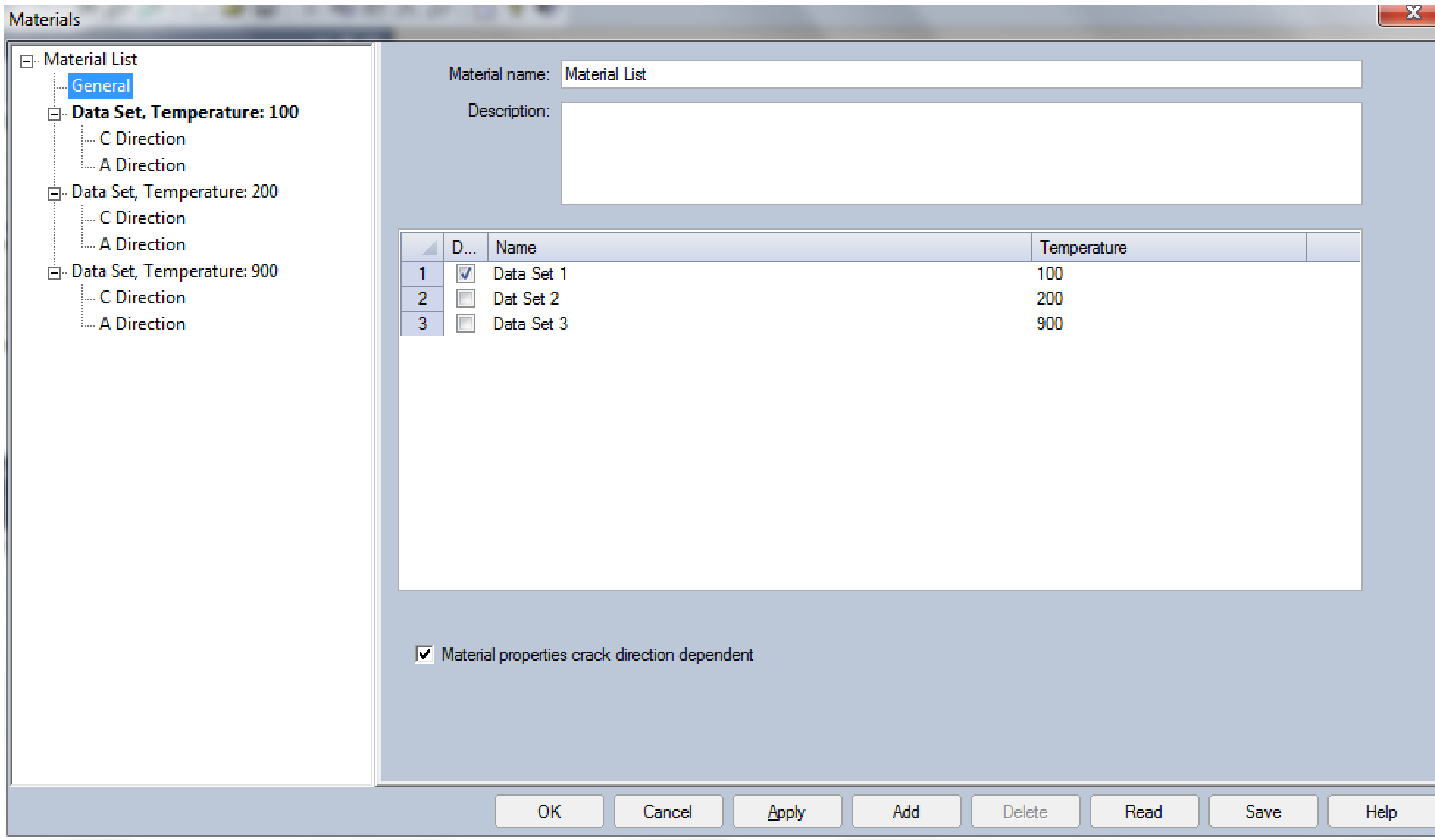
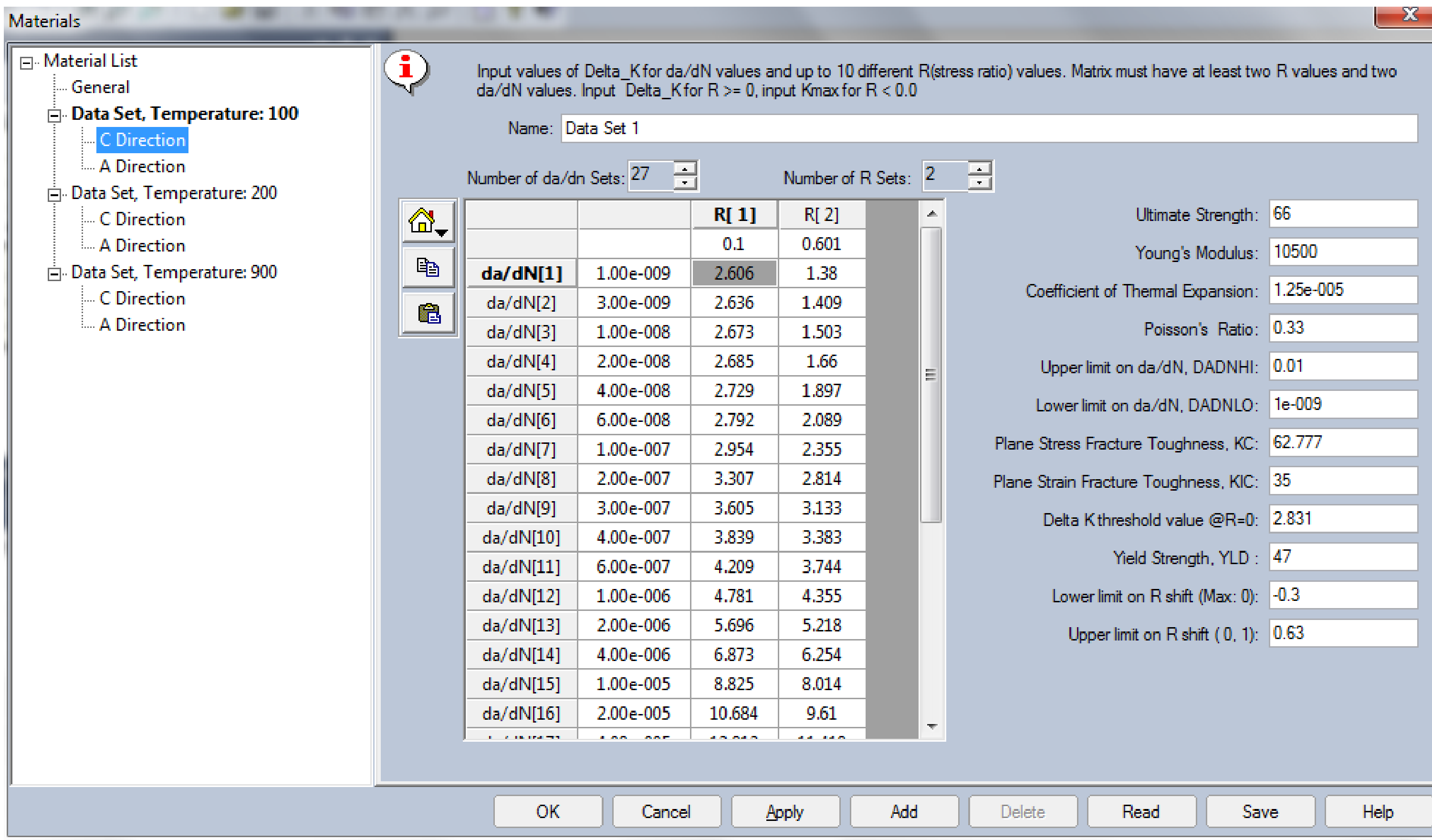
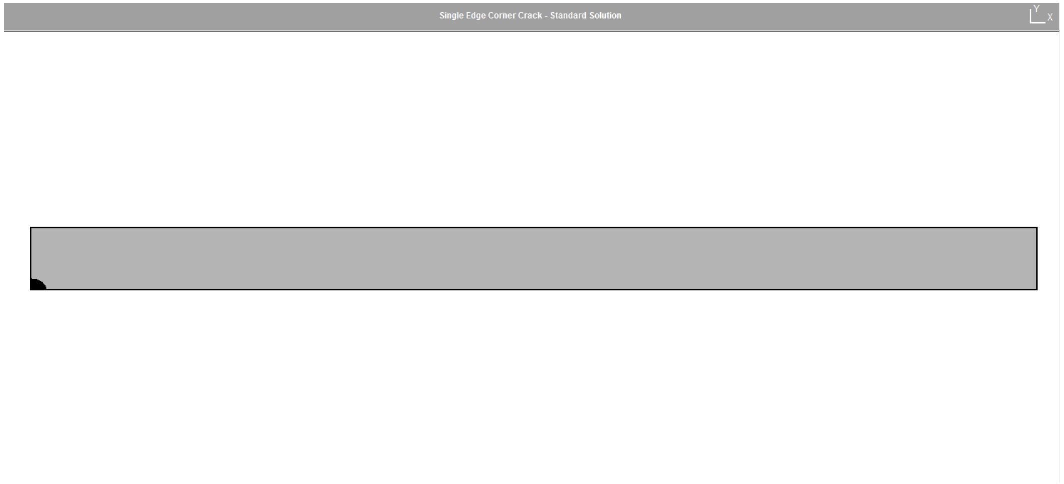
New Material features dialog changes – General



New material features dialog changes - Material set property

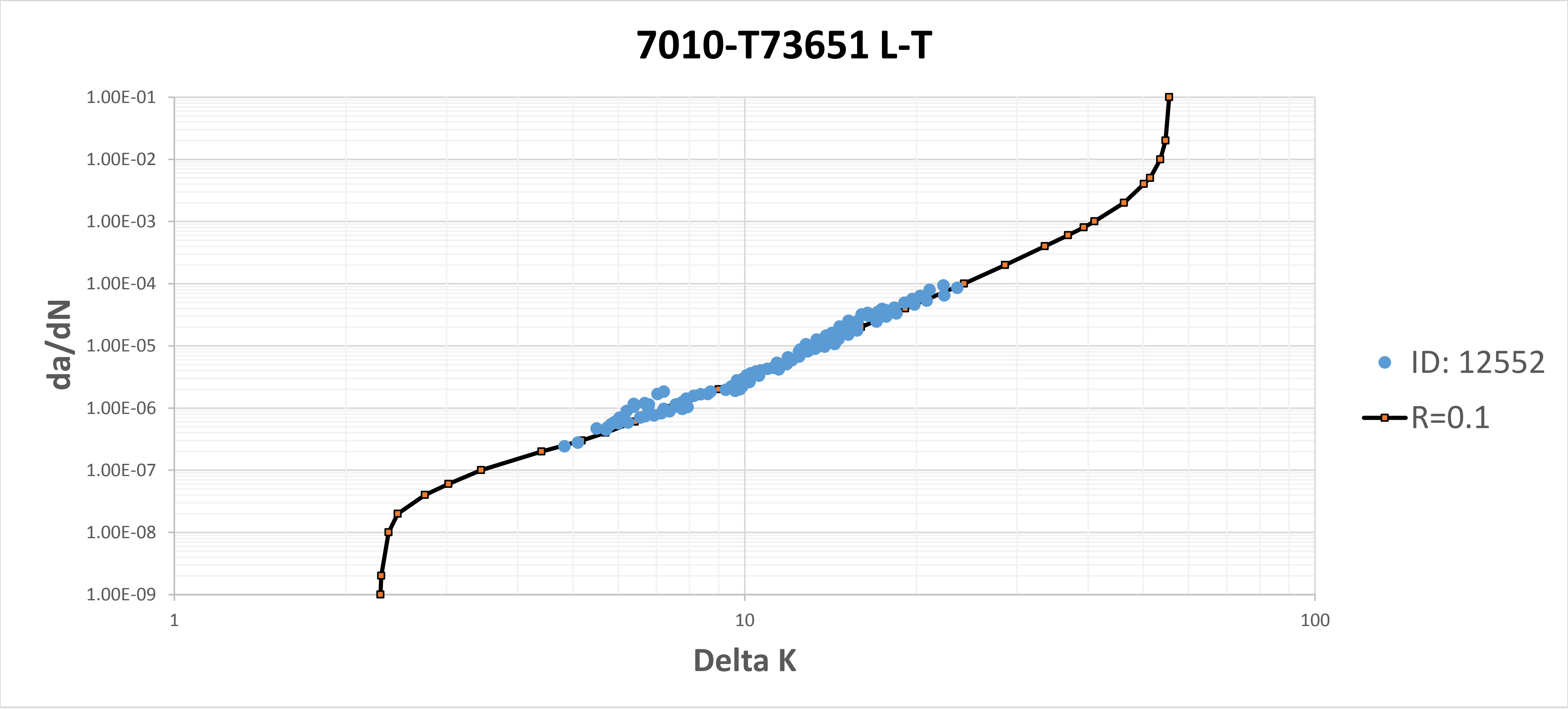


Example Problem with 7010-T73651 L-T and L-S Data

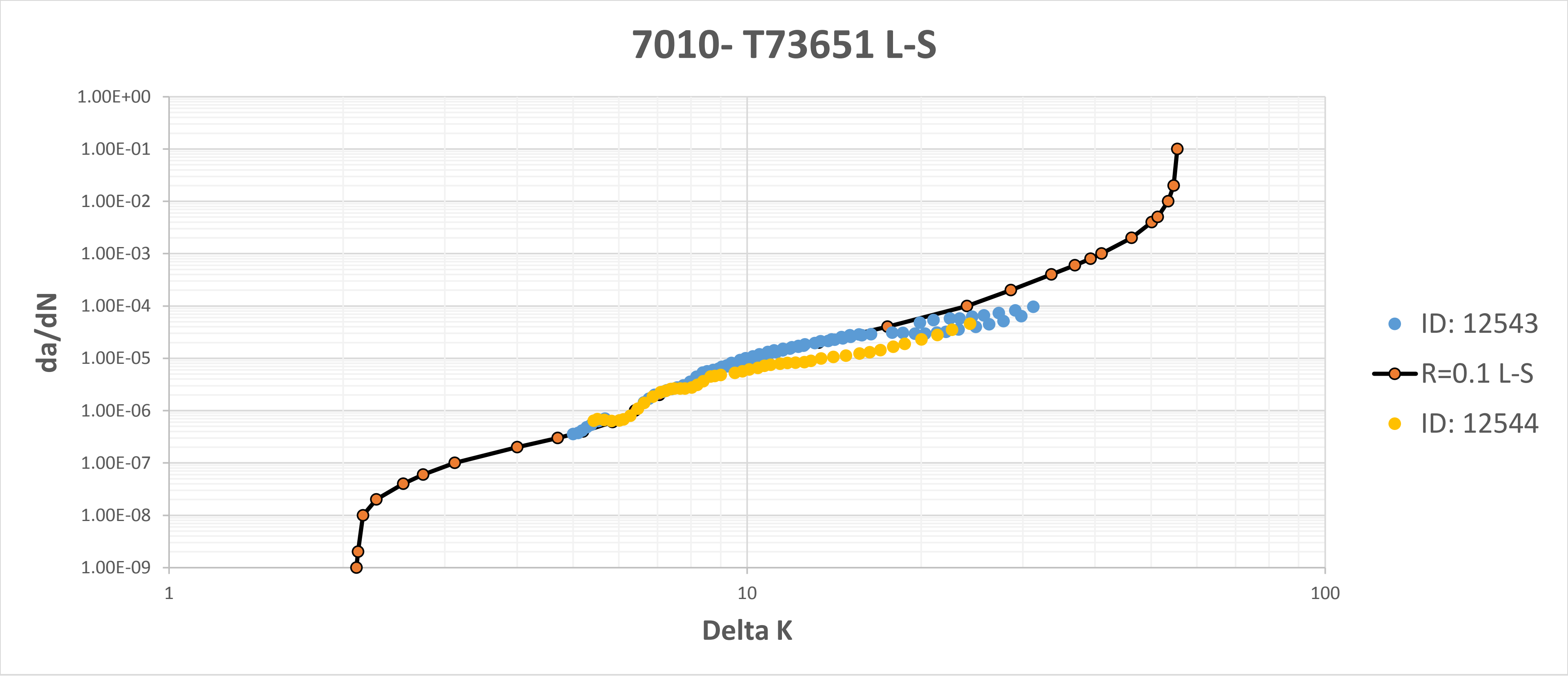


- Used Single Edge Corner Crack-Standard Solution With initial crack size for C=0.05 and A=0.05 Width=4 and Thickness=0.25
- Constant amplitude loading, SMF=14

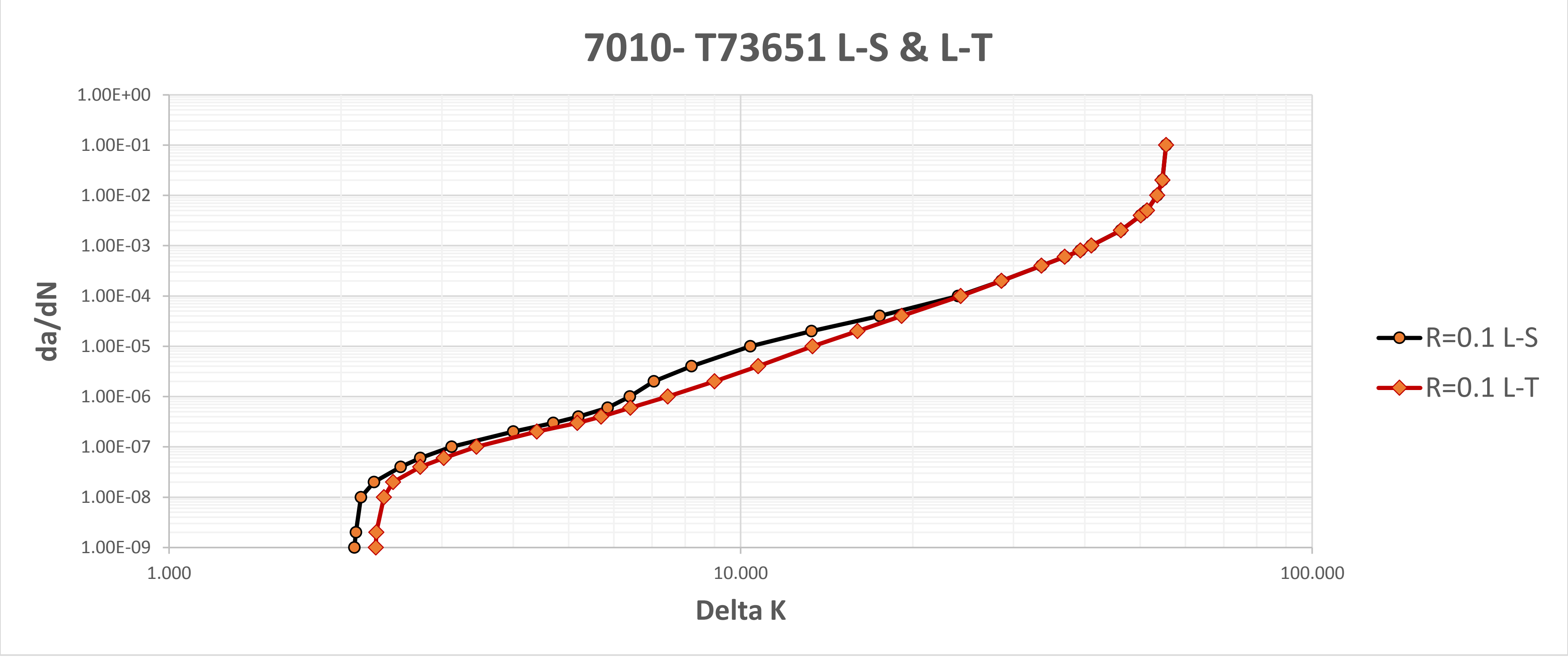
7010-T73651 L-T Data Plot for R=0.1



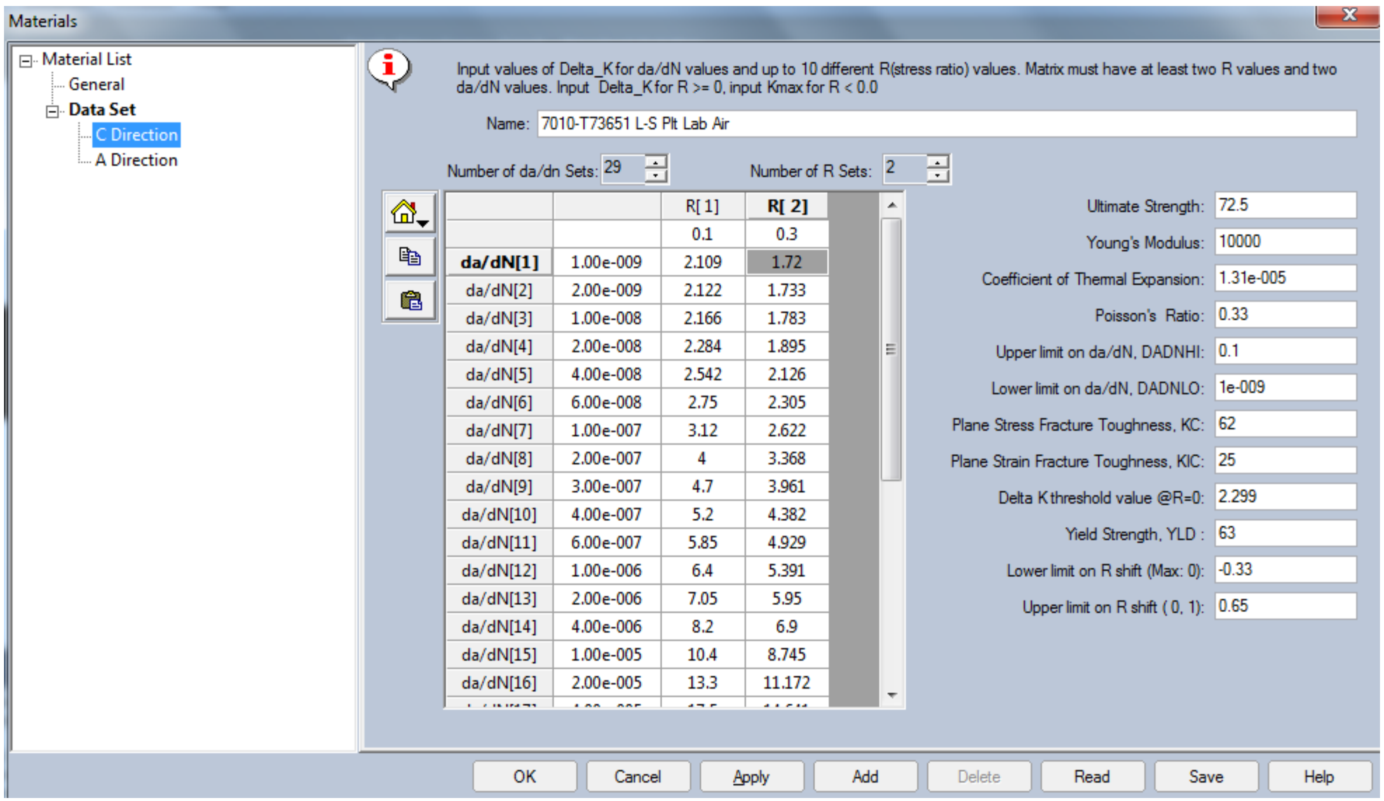
7010-T73651 L-S Data Plot for R=0.1



7010-T73651 Comparison for L-S and L-T Data Fits for R=0.1



Different material data to different crack directions example – C direction



Select the C-Direction sub header to enter the material data for the C-Direction

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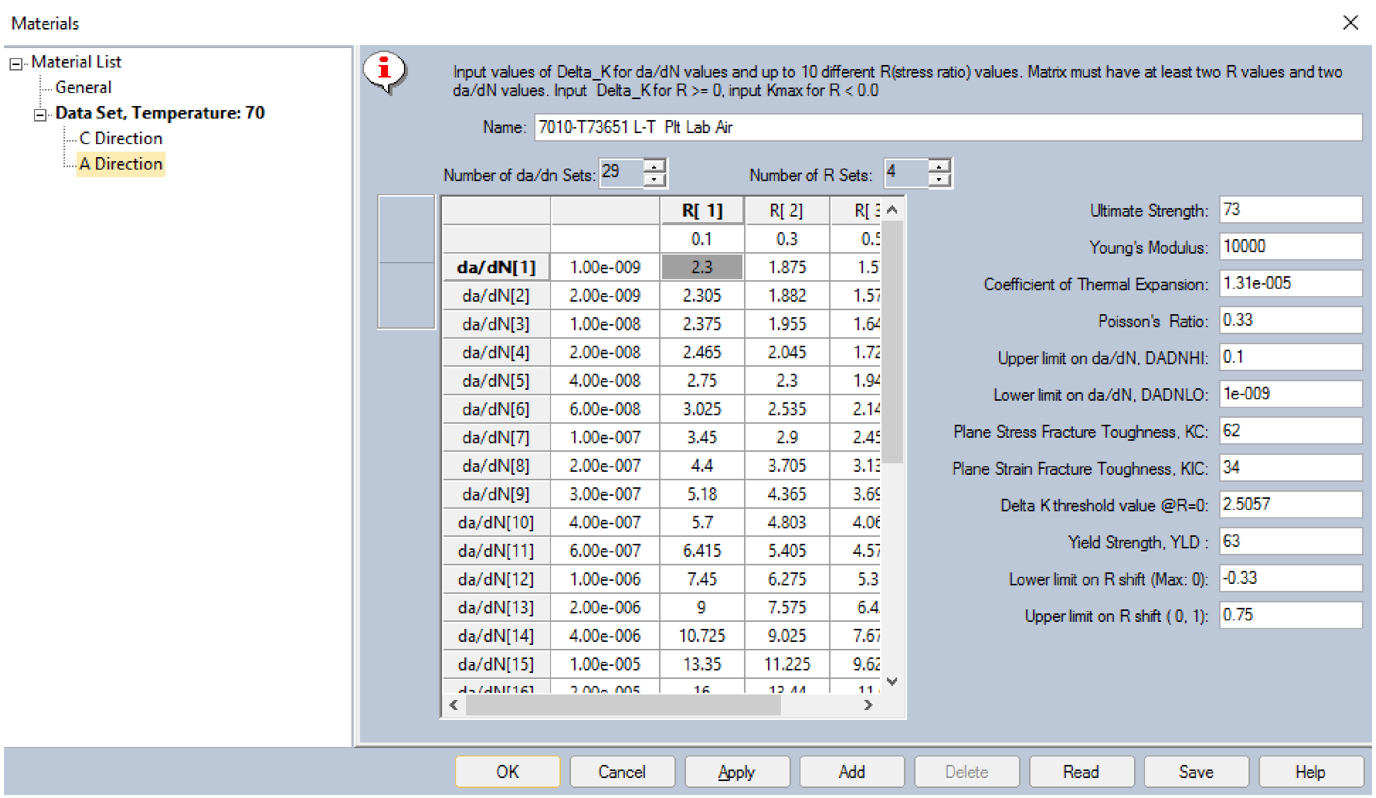
Different material data to different crack directions example – A direction



Select the A-Direction sub header to enter the material data for the A-Direction

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AFGROW Results for L-T Data in Both C and A Directions

Output

```
 C   Crack size=    1.4948   Beta Tension= 1.9687 Beta Compression= 1.9687   R(k)= 0.0000  R(final)= 0.0000            Delta k=5.9729e+001    D()/DN=1.0000e-002
Max stress =    14.000   r =  0.00       380621   Cycles   Constant amp.:       3807    Pass:  3807

*********Fracture based on ' Kmax' Criteria (current maximum stress)
 C   Crack size=    1.5748   Beta Tension= 2.0731 Beta Compression= 2.0731   R(k)= 0.0000  R(final)= 0.0000            Delta k=6.4558e+001    D()/DN=1.0000e-002
Max stress =    14.000   r =  0.00       380629   Cycles   Constant amp.:       3807    Pass:  3807

Stress State in the 'C' direction (PSC): 2
Fracture has occurred- run time:  0 hour(s)  0 minute(s)  1 second(s)
```

AFGROW Results for L-S Data in Both C and A Directions

```
Output
C  Crack size=   1.4672  Beta Tension= 1.9347 Beta Compression= 1.9347  R(k)= 0.0000  R(final)= 0.0000        Delta k=5.8152e+001  D()/DN=7.4241e-003
Max stress =   14.000  r = 0.00     257623  Cycles  Constant amp.:     2577   Pass:  2577

*********Fracture based on ' Kmax' Criteria (current maximum stress)
C  Crack size=   1.5414  Beta Tension= 2.0283 Beta Compression= 2.0283  R(k)= 0.0000  R(final)= 0.0000        Delta k=6.2489e+001  D()/DN=1.0000e-001
Max stress =   14.000  r = 0.00     257633  Cycles  Constant amp.:     2577   Pass:  2577

Stress State in the 'C' direction (PSC): 2
Fracture has occurred- run time:  0 hour(s)  0 minute(s)  1 second(s)
```

Total number of cycles= 257633

AFGROW Results for L-T Data in C-Direction and L-S in A-Direction

```
Output
 C   Crack size=    1.4717   Beta Tension= 1.9402 Beta Compression= 1.9402   R(k)= 0.0000  R(final)= 0.0000            Delta k=5.8406e+001   D()/DN=7.8965e-003
Max stress =     14.000   r =  0.00       325461   Cycles   Constant amp.:       3255    Pass:  3255

*********Fracture based on ' Kmax' Criteria (current maximum stress)
 C   Crack size=    1.5506   Beta Tension= 2.0405 Beta Compression= 2.0405   R(k)= 0.0000  R(final)= 0.0000            Delta k=6.3053e+001   D()/DN=-1.#QNBe+000
Max stress =     14.000   r =  0.00       325471   Cycles   Constant amp.:       3255    Pass:  3255

Stress State in the 'C' direction (PSC): 2
Fracture has occurred- run time:  0 hour(s)  0 minute(s)  1 second(s)
```

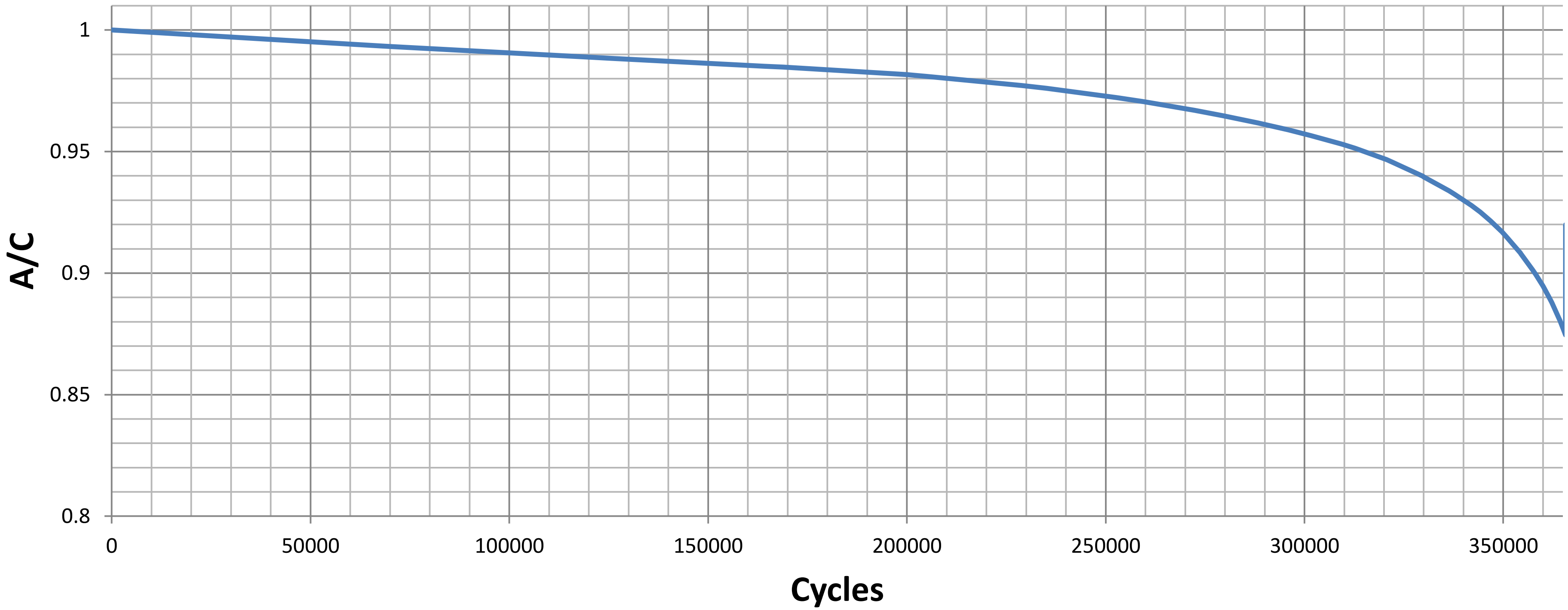
Total number of cycles= 325471

AFGROW Results for L-S Data in C-Direction and L-T in A-Direction

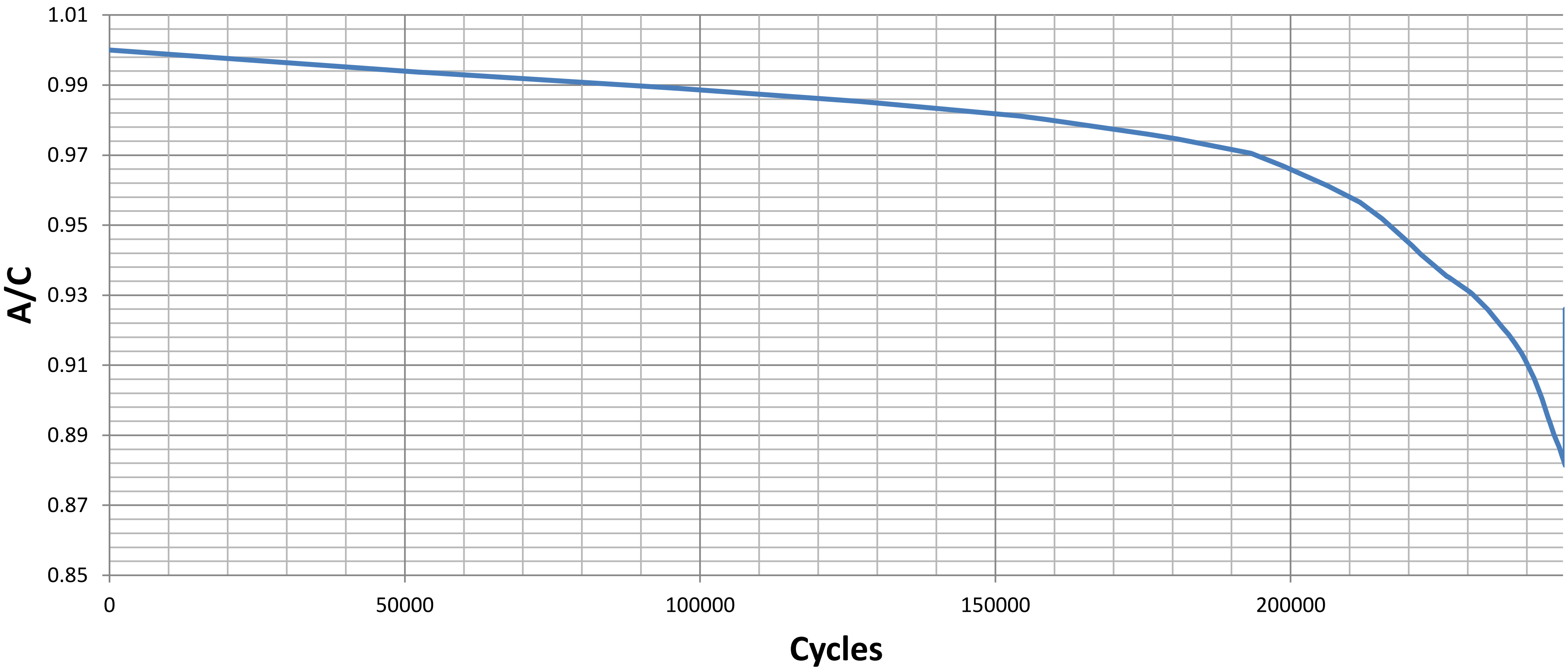
```
Output
C  Crack size=  1.5206  Beta Tension= 2.0013 Beta Compression= 2.0013  R(k)= 0.0000  R(final)= 0.0000        Delta k=6.1238e+001  D()/DN=5.2113e-002
Max stress =  14.000  r =  0.00    307382  Cycles  Constant amp.:    3074   Pass:  3074

*********Fracture based on ' Kmax' Criteria (current maximum stress)
C  Crack size=  1.6248  Beta Tension= 2.1433 Beta Compression= 2.1433  R(k)= 0.0000  R(final)= 0.0000        Delta k=6.7794e+001  D()/DN=1.0000e-001
Max stress =  14.000  r =  0.00    307384  Cycles  Constant amp.:    3074   Pass:  3074

Stress State in the 'C' direction (PSC): 2
Fracture has occurred- run time:  0 hour(s)  0 minute(s)  1 second(s)
```

Total number of cycles=307384

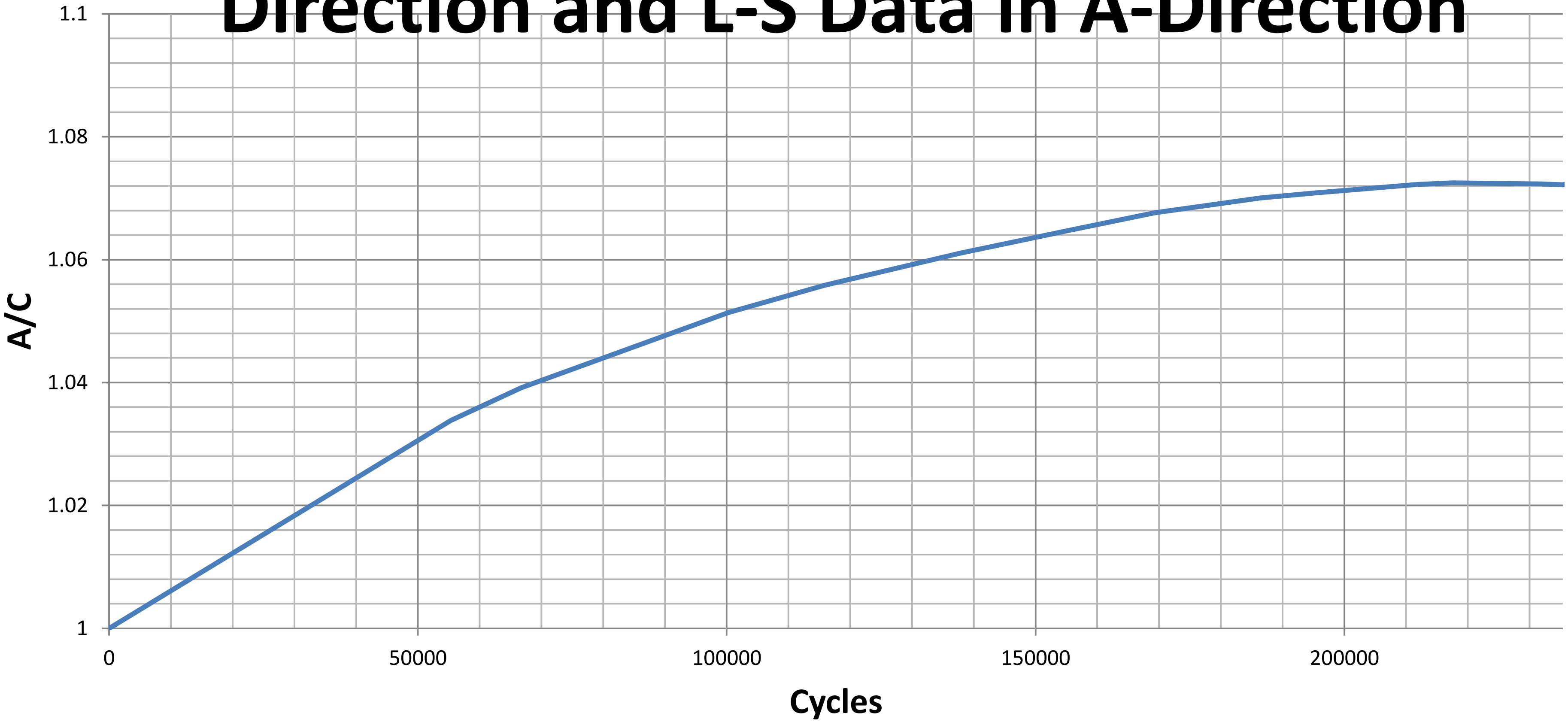
A/C vs. Cycles Plot for L-T Data in Both A and C Directions



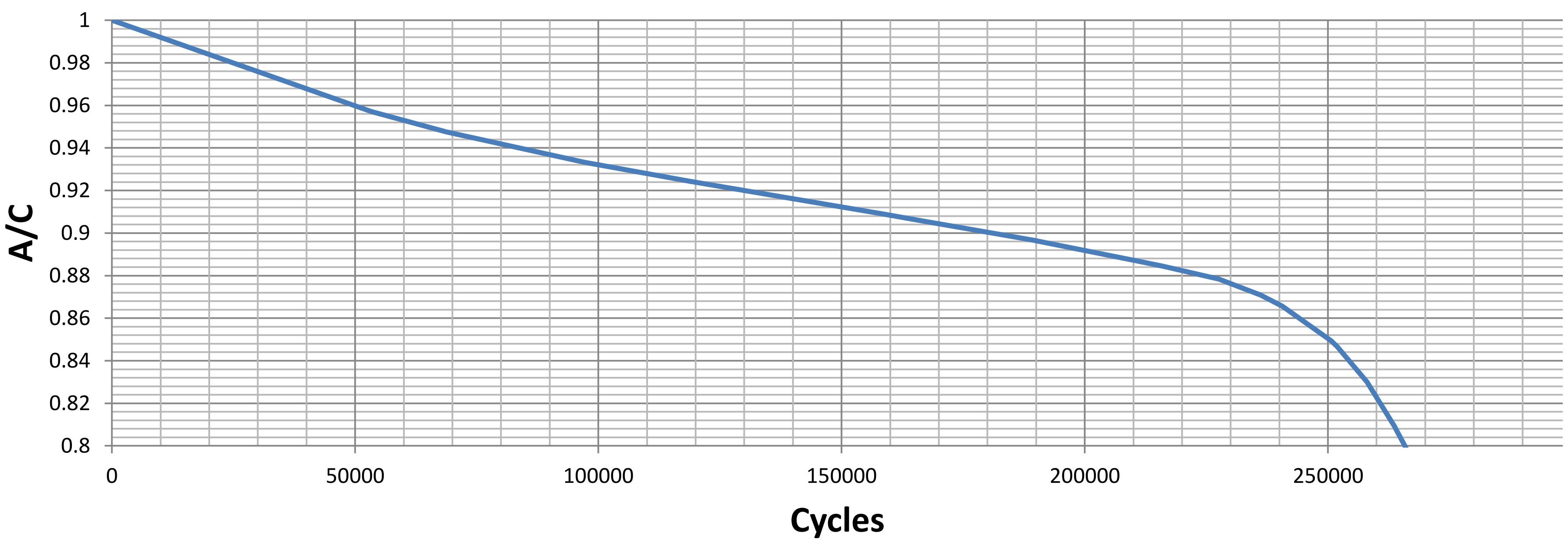
A/C vs. Cycles Plot for L-S Data in Both A and C Directions



A/C vs. Cycles Plot for L-T Data in C-Direction and L-S Data in A-Direction



A/C vs. Cycles Plot for L-S data in the C-Direction and L-T Data in the A-Direction

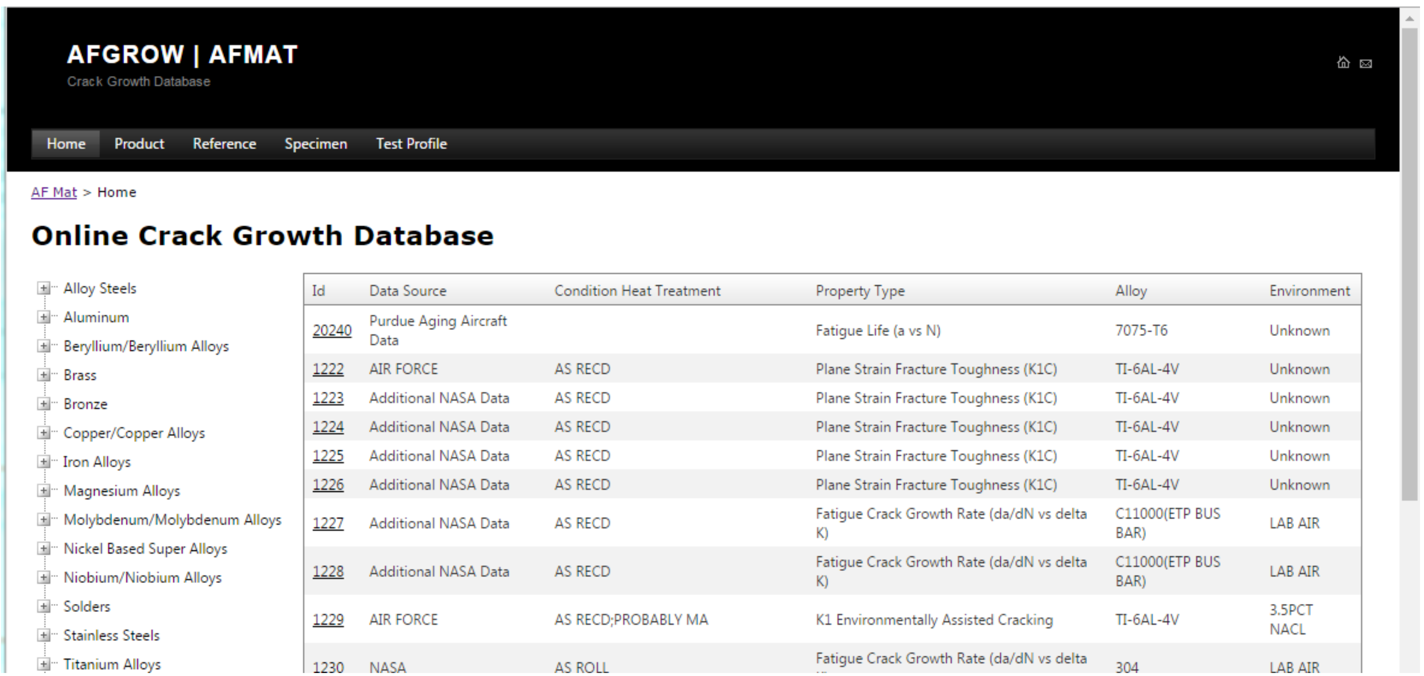


Material data from AFMAT converted to tabular lookup format in AFGROW

2000 Series	7000 Series	7000 Series (cont)	Steel	Nickel-Based Superalloy
2024-T3 L-T LAB AIR SHEET	7010-T73651 L-T LAB AIR PLATE	7075-T76511 L-T LHA EXTRUSION	15-5PH H1025	ASTROLOY 901
2024-T351 L-T LAB AIR PLATE	7050-T74 L-T LAB AIR FORGING	7150-T7751 LAB AIR PLATE	17-4PH H1025 LAB AIR T-L ROUND BAR	IN100
2024-T3511 L-T LAB AIR EXTRUTION	7050-T7451 L-T HHA	7150-T77511 LAB AIR EXTRUSION	300M	INCONEL 718 C-R LAB AIR DISC
2024-T42 L-T LAB AIR PLATE	7050-T73511 L-T HHA EXTRUSION	7175-T736 L-T HHA FORGING	316L (800)	WASPALOY
2024-T851 L-T LAB AIR PLATE	7050-T7452 L-T Forging Lab air	7175-T74 L-T LAB AIR FORGING	4340	
2124-T851 L-T LAB AIR PLATE	7050-T73651 L-T LAB AIR Plate	7178-T6 L-T LAB AIR SHEET	PH13-8Mo-H1000	
2219-T87 T-L LAB AIR PLATE	7050-T74511 L-T LA EXTRUSION	7475-T761 L-T LAB AIR SHEET	PH13-8Mo-H1050	
2324-T39 L-T LA & HHA	7050-T76511 L-T LAB AIR EXTRUSION	7475-T7351 L-T HHA PLATE	A508 T-L PWR H2O FORGING	
2091-T8 T-L HHA PLT & SHT	7050-T76511 L-T STW EXTRUTION	7475-T7651 L-T LAB AIR PLATE		
2090-T86 T-L LAB AIR TEE EXTRUSION	7075-T76 L-T LHA SHEET	7475-T7351 L-T LAB AIR PLATE		
	7075-T651 L-T LAB AIR Plt & Extr	X7090-T7E69 S-T GN2 Plate		
	7075-T7351 L-T LAB AIR PLATE			
	7075-T73511 L-T LAB AIR EXTRUSION			
	7075-T6 L-T LAB AIR SHEET			
	7075-T7651 L-T LHA PLATE			

Material data from AFMAT converted to tabular lookup format in AFGROW

- Will be distributed through AFMAT
- Material data will be in new tabular-Lookup format that is going to be introduced in AFGROW 5.3


AFGROW | AFMAT

Crack Growth Database

Home Product Reference Specimen Test Profile

AF Mat > Home

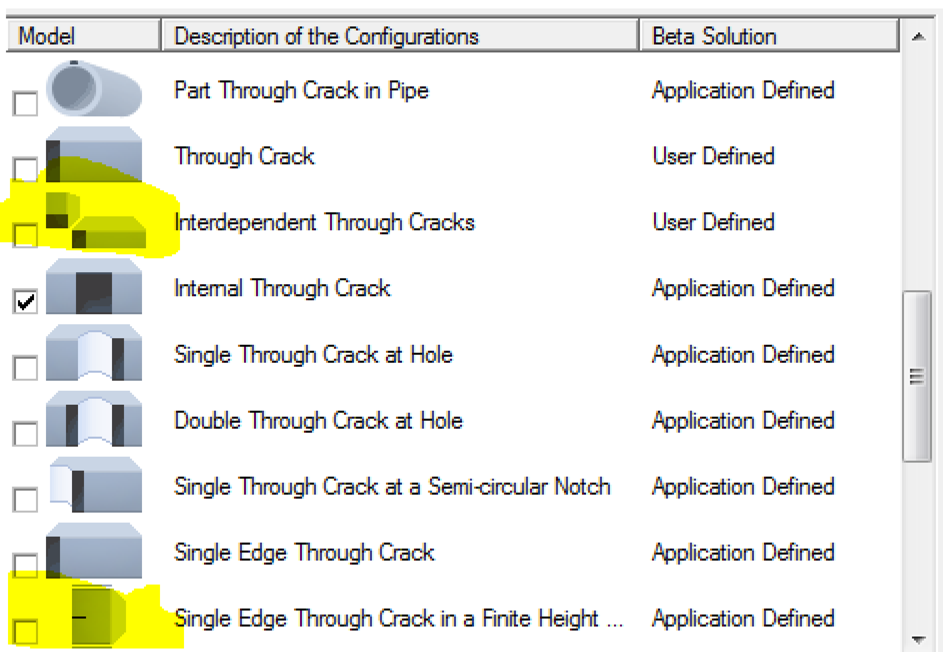
Online Crack Growth Database

- Alloy Steels
- Aluminum
- Beryllium/Beryllium Alloys
- Brass
- Bronze
- Copper/Copper Alloys
- Iron Alloys
- Magnesium Alloys
- Molybdenum/Molybdenum Alloys
- Nickel Based Super Alloys
- Niobium/Niobium Alloys
- Solders
- Stainless Steels
- Titanium Alloys

Id	Data Source	Condition Heat Treatment	Property Type	Alloy	Environment
20240	Purdue Aging Aircraft Data		Fatigue Life (a vs N)	7075-T6	Unknown
1222	AIR FORCE	AS RECD	Plane Strain Fracture Toughness (K1C)	TI-6AL-4V	Unknown
1223	Additional NASA Data	AS RECD	Plane Strain Fracture Toughness (K1C)	TI-6AL-4V	Unknown
1224	Additional NASA Data	AS RECD	Plane Strain Fracture Toughness (K1C)	TI-6AL-4V	Unknown
1225	Additional NASA Data	AS RECD	Plane Strain Fracture Toughness (K1C)	TI-6AL-4V	Unknown
1226	Additional NASA Data	AS RECD	Plane Strain Fracture Toughness (K1C)	TI-6AL-4V	Unknown
1227	Additional NASA Data	AS RECD	Fatigue Crack Growth Rate (da/dN vs delta K)	C11000(ETP BUS BAR)	LAB AIR
1228	Additional NASA Data	AS RECD	Fatigue Crack Growth Rate (da/dN vs delta K)	C11000(ETP BUS BAR)	LAB AIR
1229	AIR FORCE	AS RECD;PROBABLY MA	K1 Environmentally Assisted Cracking	TI-6AL-4V	3.5PCT NACL
1230	NASA	AS ROLL	Fatigue Crack Growth Rate (da/dN vs delta	304	LAB AIR

New Classic Models

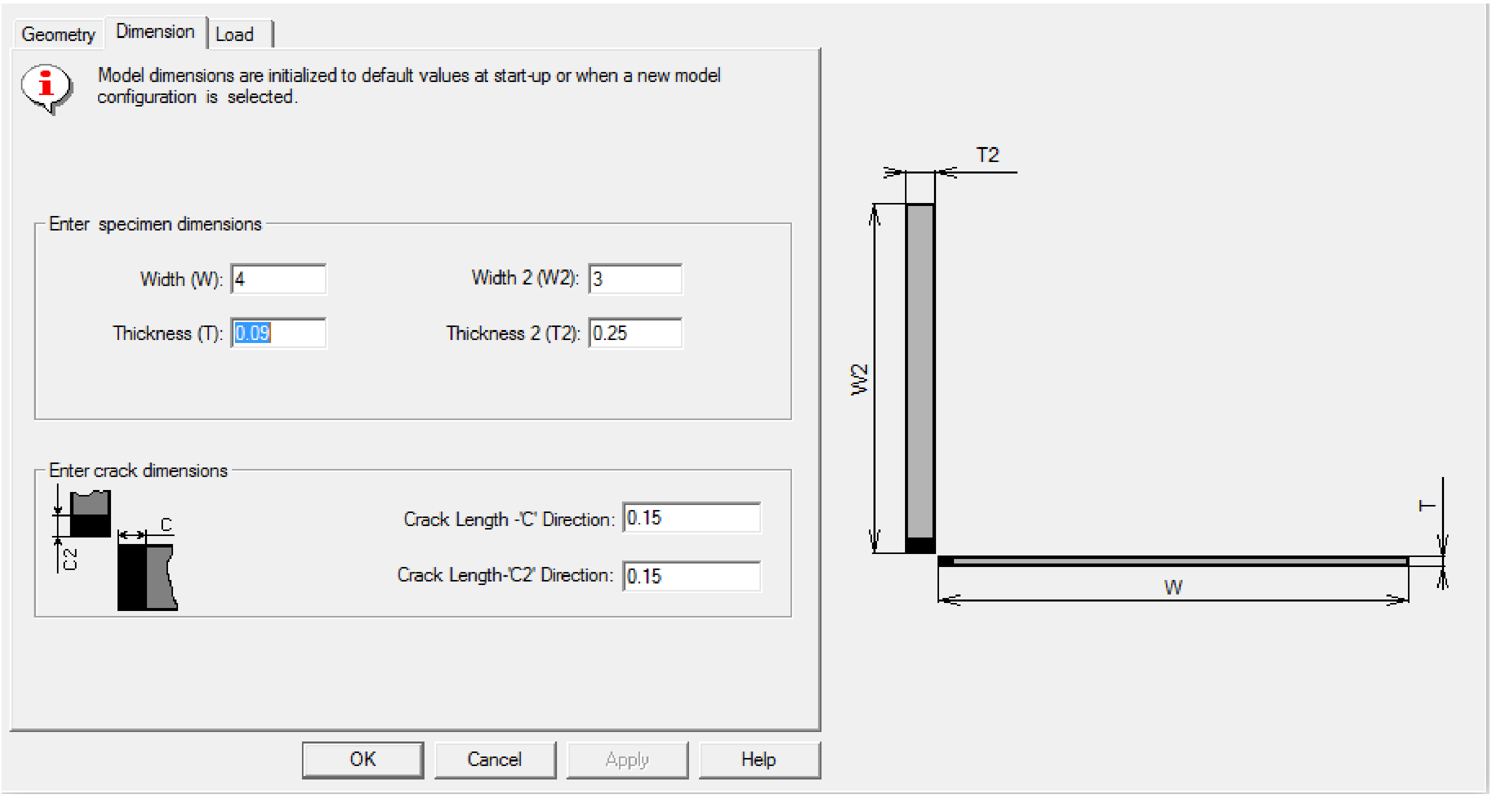
- Single corner crack model with the finite height
- 2 inter-dependent through cracks that can be assigned different plate thickness values



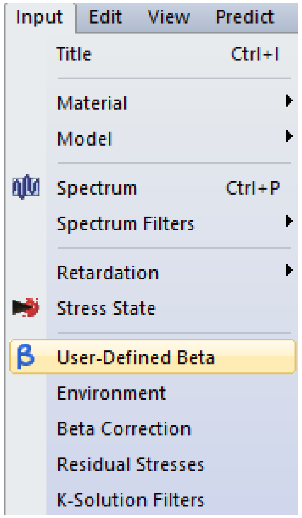
Model	Description of the Configurations	Beta Solution
☐	Part Through Crack in Pipe	Application Defined
☐	Through Crack	User Defined
☐	Interdependent Through Cracks	User Defined
☑	Internal Through Crack	Application Defined
☐	Single Through Crack at Hole	Application Defined
☐	Double Through Crack at Hole	Application Defined
☐	Single Through Crack at a Semi-circular Notch	Application Defined
☐	Single Edge Through Crack	Application Defined
☐	Single Edge Through Crack in a Finite Height ...	Application Defined

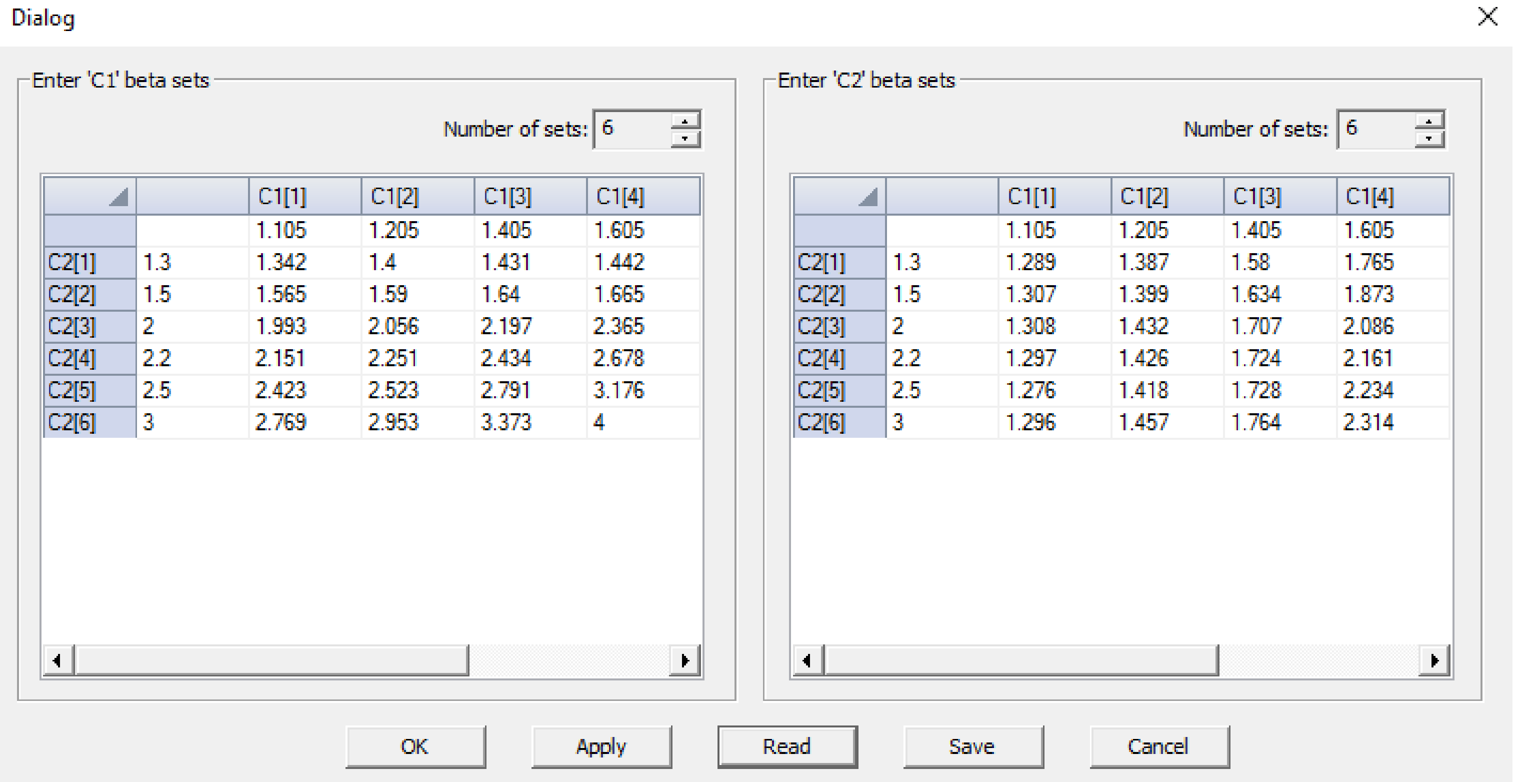
Two inter-dependent through cracks model

Model Geometry/Dimension/Load Dialog



User Defined Beta Dialog





Enter 'C1' beta sets

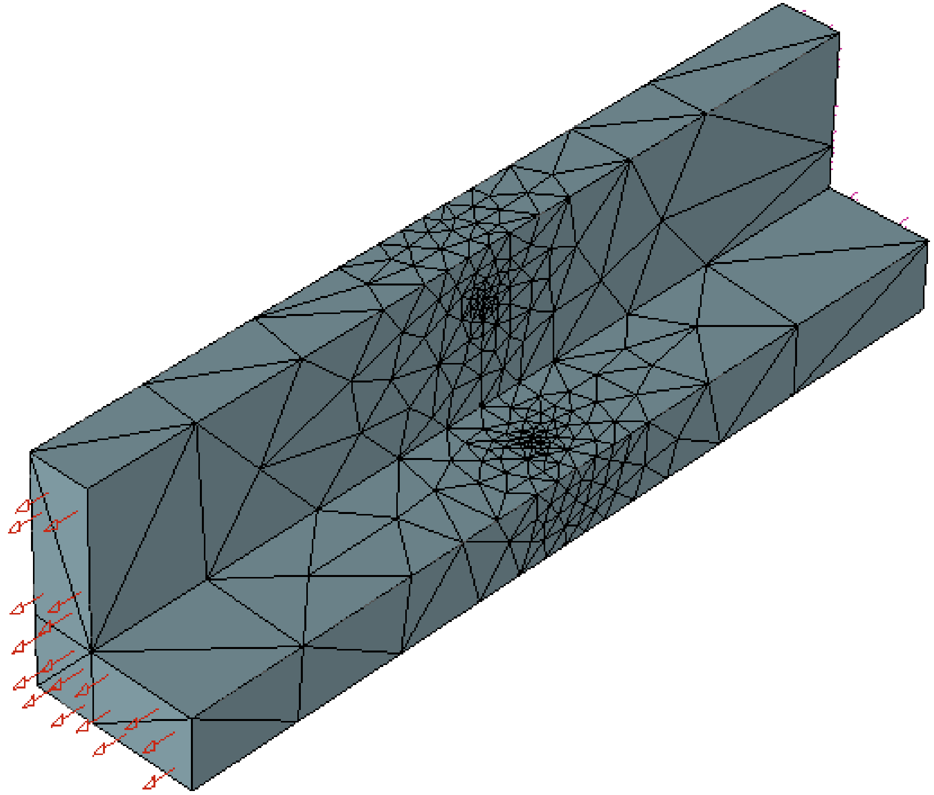
		C1[1]	C1[2]	C1[3]	C1[4]
		1.105	1.205	1.405	1.605
C2[1]	1.3	1.342	1.4	1.431	1.442
C2[2]	1.5	1.565	1.59	1.64	1.665
C2[3]	2	1.993	2.056	2.197	2.365
C2[4]	2.2	2.151	2.251	2.434	2.678
C2[5]	2.5	2.423	2.523	2.791	3.176
C2[6]	3	2.769	2.953	3.373	4

Enter 'C2' beta sets

		C1[1]	C1[2]	C1[3]	C1[4]
		1.105	1.205	1.405	1.605
C2[1]	1.3	1.289	1.387	1.58	1.765
C2[2]	1.5	1.307	1.399	1.634	1.873
C2[3]	2	1.308	1.432	1.707	2.086
C2[4]	2.2	1.297	1.426	1.724	2.161
C2[5]	2.5	1.276	1.418	1.728	2.234
C2[6]	3	1.296	1.457	1.764	2.314

- New Beta table Files are (*.linx)

Example of FEA model

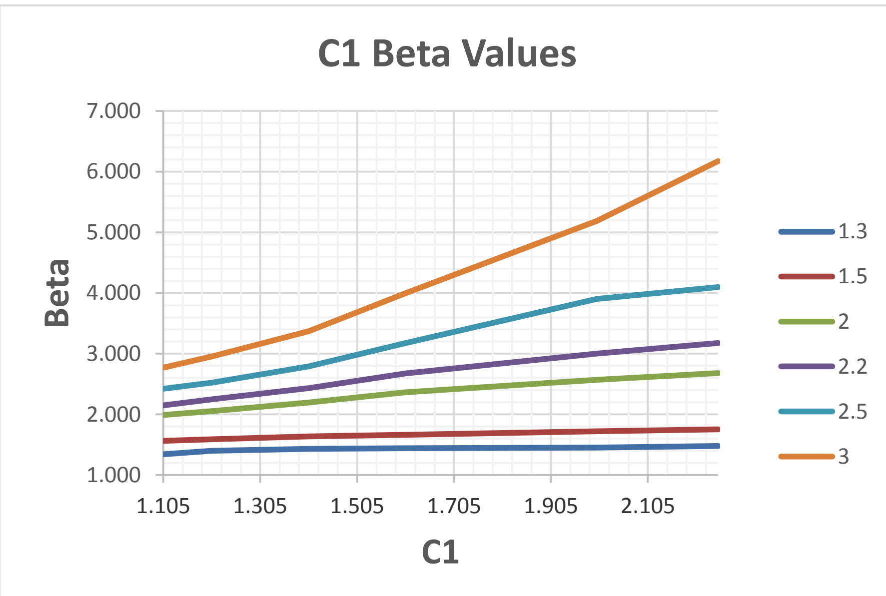


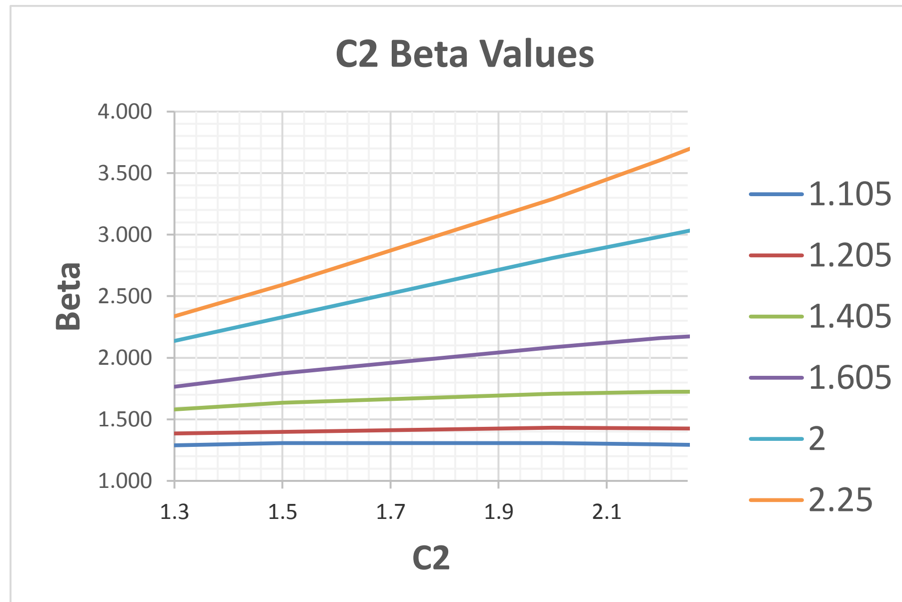
Beta Tables Generated FEA

C1 Beta Table							
		C1[1]	C1[2]	C1[3]	C1[4]	C1[5]	C1[6]
		1.105	1.205	1.405	1.605	2	2.25
C2[1]	1.3	1.342	1.400	1.431	1.442	1.457	1.479
C2[2]	1.5	1.565	1.590	1.640	1.665	1.721	1.752
C2[3]	2	1.993	2.056	2.197	2.365	2.568	2.682
C2[4]	2.2	2.151	2.251	2.434	2.678	3.000	3.174
C2[5]	2.5	2.423	2.523	2.791	3.176	3.902	4.100
C2[6]	3	2.769	2.953	3.373	4.000	5.190	6.172

C2 Beta Table							
		C1[1]	C1[2]	C1[3]	C1[4]	C1[5]	C1[6]
		1.105	1.205	1.405	1.605	2	2.25
C2[1]	1.3	1.289	1.387	1.580	1.765	2.136	2.336
C2[2]	1.5	1.307	1.399	1.634	1.873	2.330	2.593
C2[3]	2	1.308	1.432	1.707	2.086	2.810	3.290
C2[4]	2.2	1.297	1.426	1.724	2.161	2.984	3.607
C2[5]	2.5	1.276	1.418	1.728	2.234	3.252	4.114
C2[6]	3	1.296	1.457	1.764	2.314	3.632	4.987

Beta Value Plots



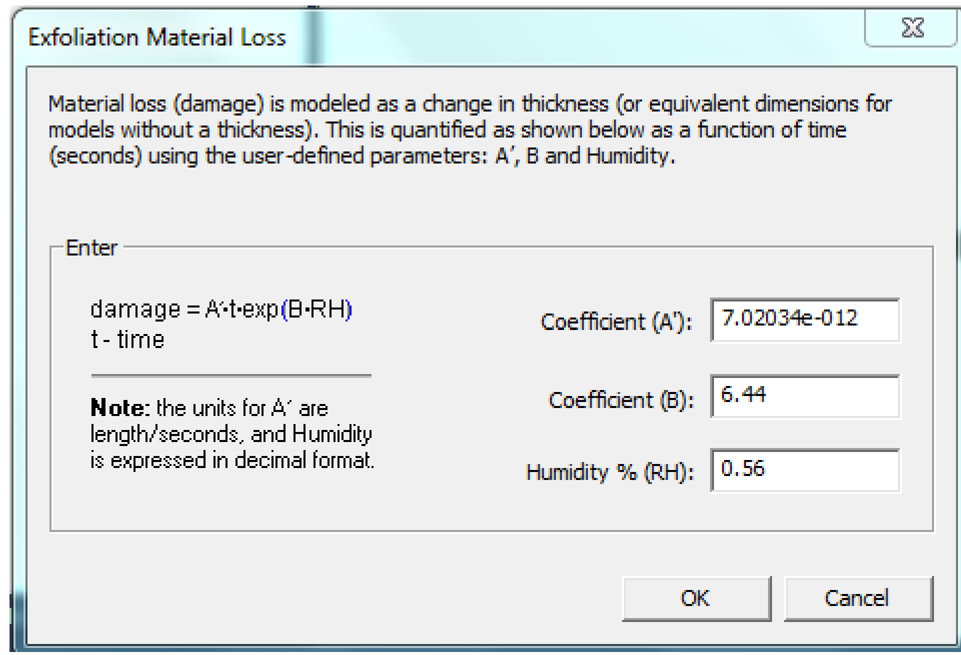


Corrosion

- d(geometry)/dtime models: intergranular corrosion model, exfoliation corrosion modeling, and user defined equation model.
- Only one of three can be used at the same time
- Initial crack size: pitting and crevice model. Only one of two can be used at the same time
- Pitting model in not time dependent, it calculates maximum possible pit size under given environment for a specified material
- Crevice model calculated time that is required for crevice to develop under given environment for a specified material. Can be used similar to initiation model in AFGROW. Require time dependent spectrum in the old .st3 or new .spx format
- Developed under contract with SAFE

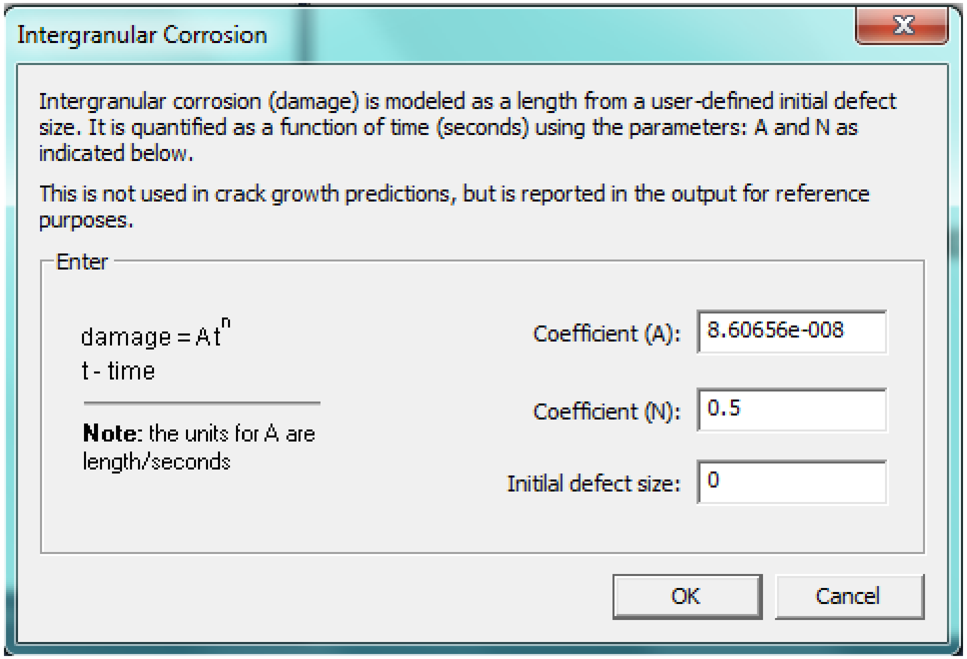
Corrosion - Exfoliation

- Require time dependent spectrum in the old .st3 or new .spx format
- Changes thickness/thickness equivalent dimension
- Depends on material properties and humidity



Corrosion - Intergranular

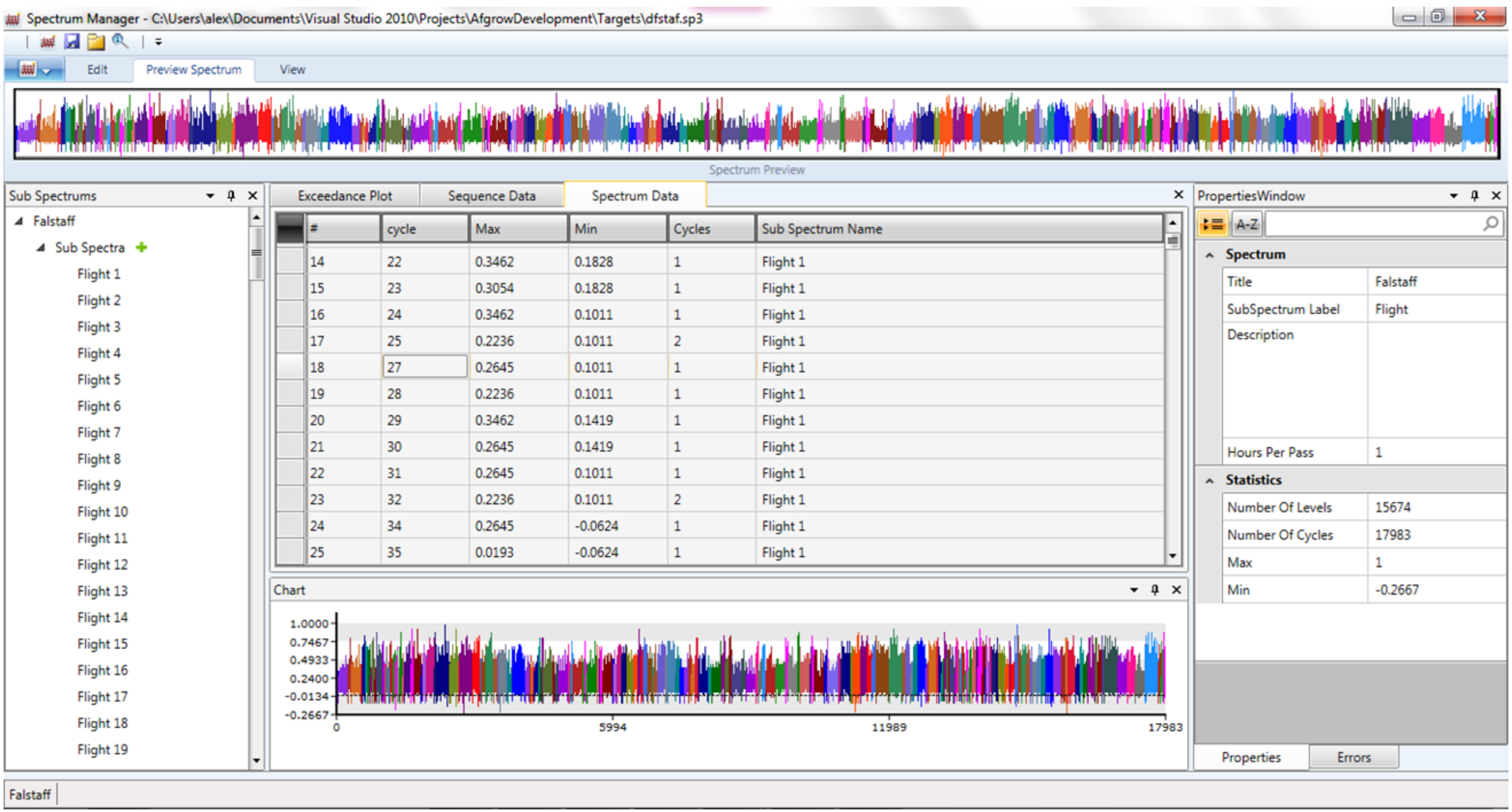
- Require time dependent spectrum in the old .st3 or new .spx format
- Modeled as length from user defined initial defect size
- Not used in the crack growth predictions, but is reported in the output for reference purposes
- Depends on material and environment properties



LexTech

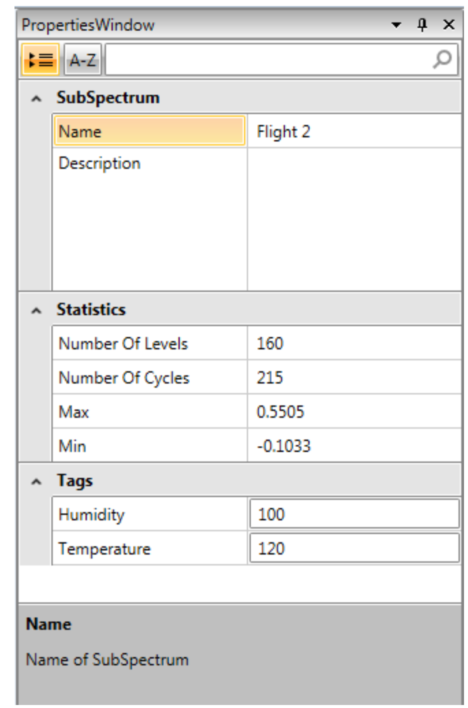
AFGROW.NET

Spectrum Manager



Spectrum Manager Overview

- Visual spectrum design
- Spectrum level reordering
- Sub-spectra organized in any user-defined sequence
- Sub-spectra may be placed in the sequence more than once
- Sub-spectra may be re-ordered in the sequence
- Spectrum statistics at a glance
- Exceedance curve
- Sub-spectra tagging for future analysis
- Synchronized data views
- Spectrum level damage tagging



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- AFGROW Customers and Consortium Members