

AFGROW Workshop 2017

AFGROW Release 5.3

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AFGROW Release 5.3

The screenshot displays the AFGROW software interface. On the left, a 'Crack Growth Rate Data' plot shows da/dN on a logarithmic y-axis (from $1e-10$ to $1e-01$) versus ΔK on a logarithmic x-axis (from 0.1 to 10). A red curve represents the data, with a note indicating $R= 0.00$. Below the plot, an 'Output' window contains a text area with a comment: 'This space for comments'. In the center, a 'Predict Function Preferences' dialog box is open, with the 'Bending' tab selected. The dialog includes an information icon and text: 'The out-of-plane (transverse) bending solution for internal and edge through cracks is approximated using the axial load solution multiplied by a bending correction factor. The default correction factor is two-thirds.' Below this, there is a 'Select' section with a checked option 'Use default correction factor' and a text field for 'Correction factor' containing the value '0.6666666666666666'. A note states: 'User defined correction factor value must range between 1/3 and 2/3'. The dialog has 'OK', 'Cancel', 'Save', and 'Default' buttons. On the right, the 'Properties' panel shows specimen details: Name 'Specimen' and Width '4.000000'. The 'ToolBox' panel lists object types: Hole, Countersunk Hole, Through Crack, Part-Through Crack, and Slot. The main window shows a 3D model of a specimen with a crack. The status bar at the bottom indicates 'English' and 'PASS: 999999'.

AFGROW Release 5.3 – Highlights

- Release Candidate Availability Date - September 27, 2017
- 64 bit version
- Multilingual support
- Material Database redesign and outgoing data update – more than 2000 new material tests will be loaded. A-10, T-38, NRC and additional Air Force provided data.
- New downloadable material data in tabular lookup format will available online
- Spectrum Manager to create and edit spectra included in the release

AFGROW Release 5.3 – New Functionality

- Numerous K-solution changes/enhancements
- Ability to use different material data as a function of spectrum level
- Ability to apply different material data to different crack directions
- Corrosion Effects
 - Exfoliation
 - Intergranular
 - Pitting
- Added a new spectrum format that supports above changes and future enhancements
- Ability to open read only material data from the network or online folder. System administrator managed feature.

AFGROW Release 5.3 – New K-Solution Functionality

- 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:
 - Classic edge crack
 - Classic double edge crack
 - Classic through crack
 - All advanced cracks where bending was not available with the exception of crack at slot
- New solution for a corner crack at the countersink knuckle
- Bearing solution for advanced through crack(s) at a hole
- 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%
- Single edge crack model with the finite height – provided by SAFE
- Added global “Constrained” property for advanced model in-plane bending - only applicable for notch solutions.

64 Bit AFGROW Performance Test

Advanced double cracked hole with offset



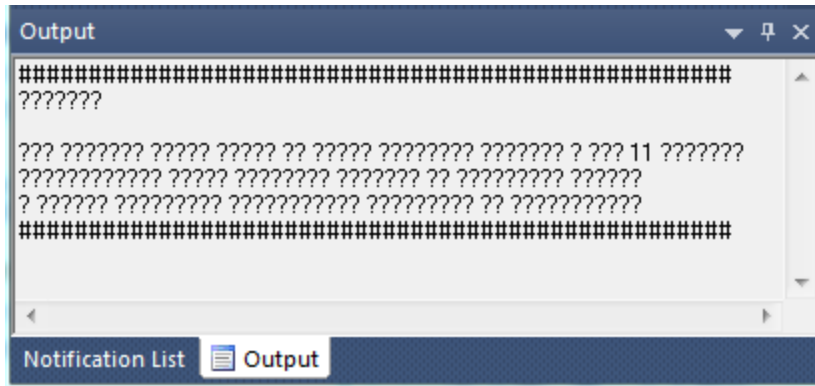
Model	Spectrum	Time 5.2 (sec)	Time 5.3 (sec)	Difference
Multipoint	FALSTAF	122	90	35.56%
Multipoint	Const Amplitude	8	6	33.33%
2 points	FALSTAF	73	62	17.74%
2 points	Const Amplitude	5	4	25.00%

32 to 64 bit upgrade was sponsored by APES

Multilingual Support

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

5.02

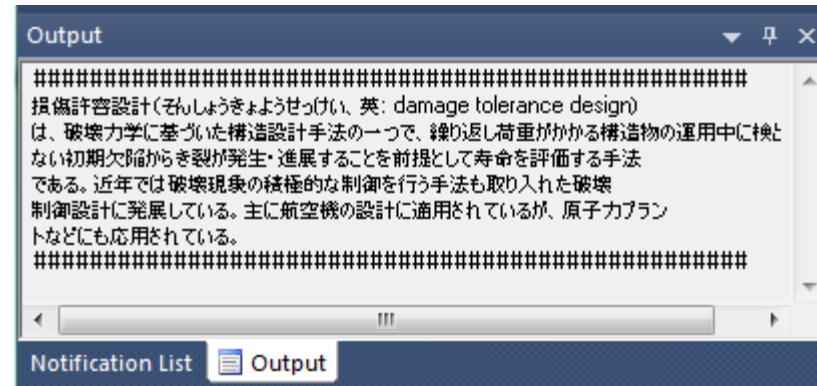


Output

```
#####  
??????  
  
?? ???? ???? ???? ?? ???? ?????? ?????? ? ?? 11 ??????  
????????? ???? ?????? ?????? ?? ?????? ??????  
? ?????? ?????? ?????? ?????? ?? ?????? ??????  
#####
```

Notification List Output

5.03



Output

```
#####  
損傷許容設計(そんしやうきようせつけい、英: damage tolerance design)  
は、破壊力学に基づいた構造設計手法の一つで、繰り返し荷重がかかる構造物の運用中に検  
ない初期欠陥からき裂が発生・進展することを前提として寿命を評価する手法  
である。近年では破壊現象の積極的な制御を行う手法も取り入れた破壊  
制御設計に発展している。主に航空機の設計に適用されているが、原子力プラ  
ントなどにも応用されている。  
#####
```

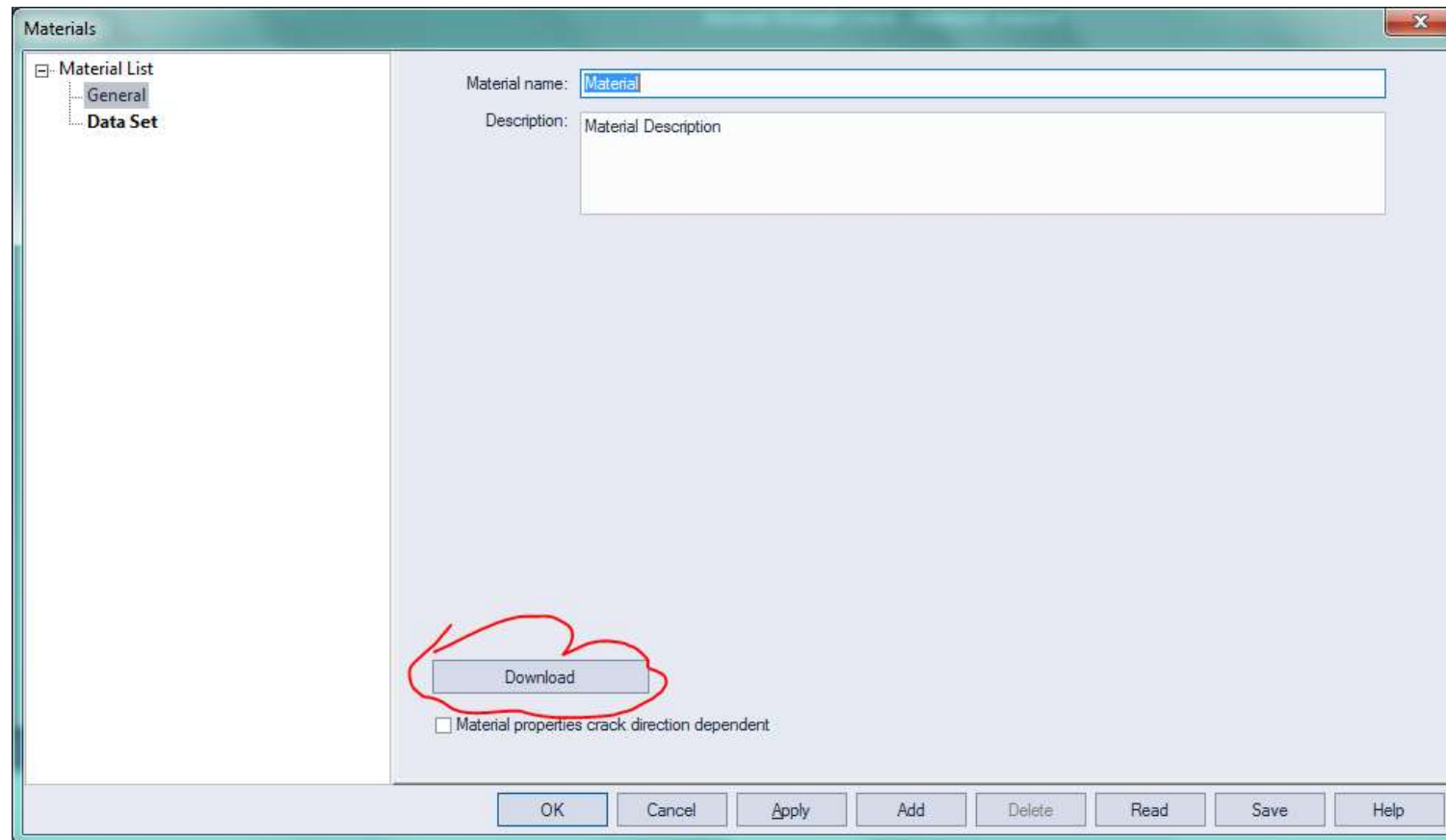
Notification List Output

Network or Online Access to Material Data

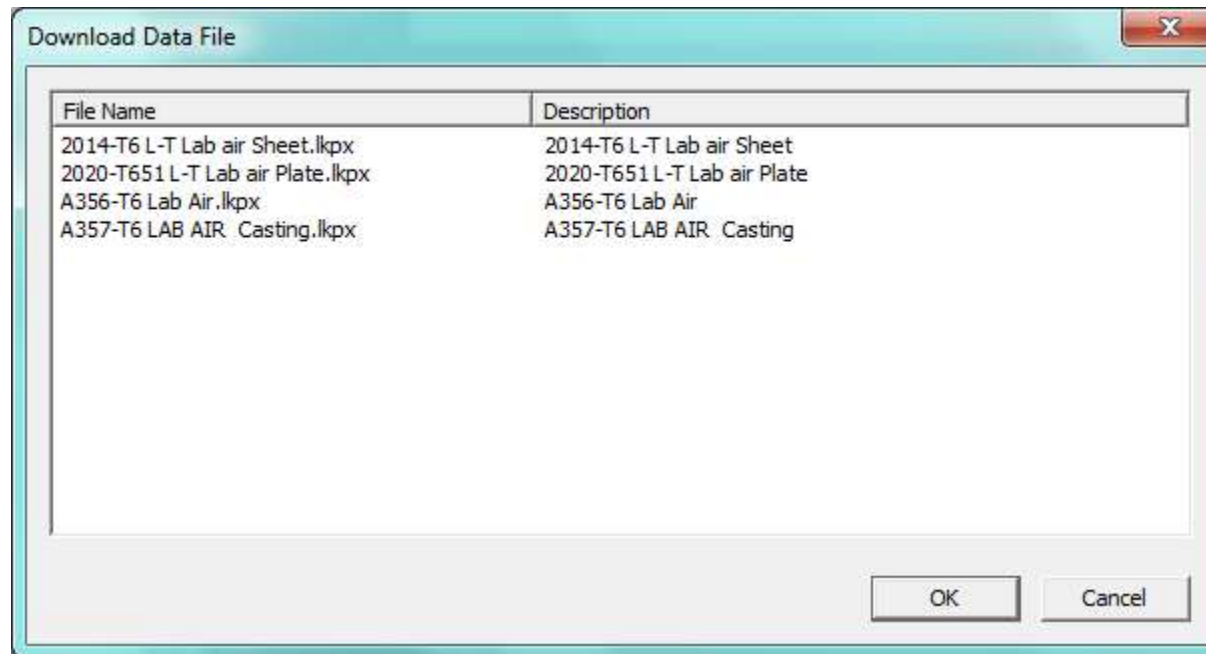
- Only tabular lookup format right now
- Require modification to the AFGROW configuration file and can be done only by administrator
- Require a data configuration file that points to all material data files
- Material files need to be in the lkpX (XML based format)

```
</configuration>
<appSettings>
  <add key="MaterialLookupListUrl" value="http://www.afgrow.net/material/MaterialLookupList.xml" />
  <!--<add key="MaterialLookupListUrl" value="Z:\ServerFolders\Users\Alex\XML-Material-Data_load\MaterialLookupList.xml" />-->
</appSettings>
<custom.settings>
```

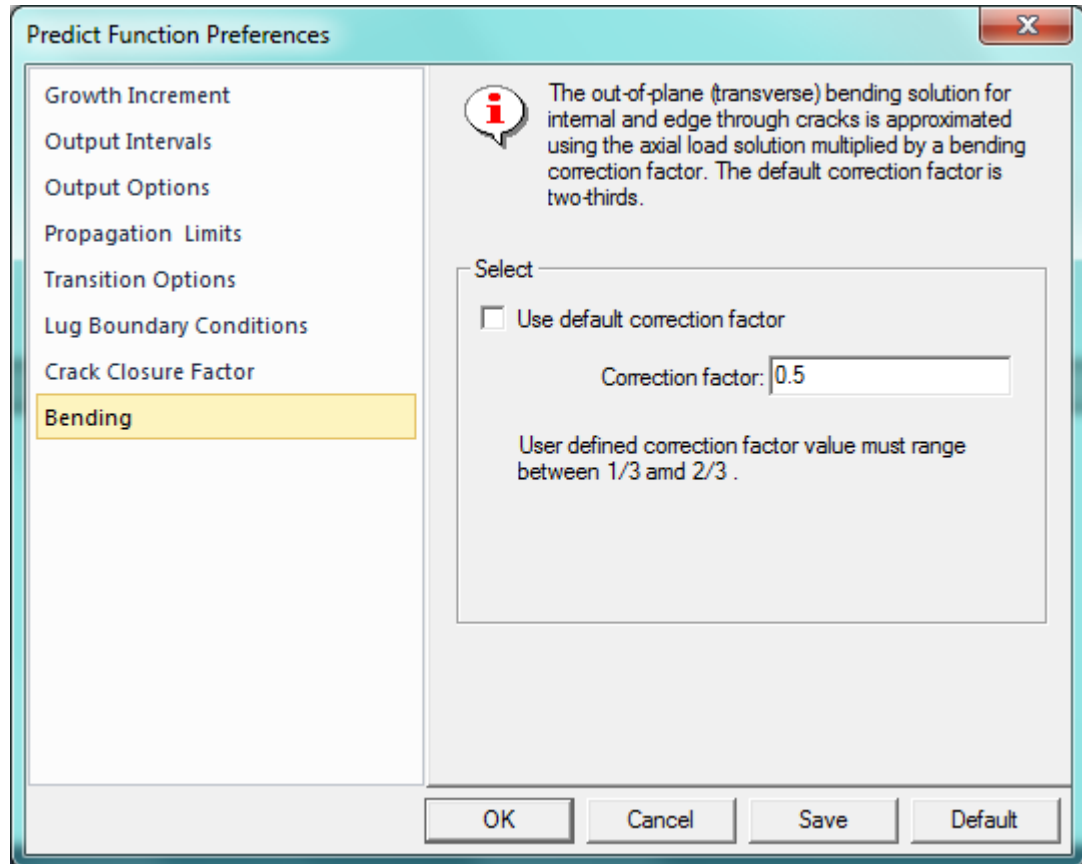

Network or Online Access to Material Data



Network or Online Access to Material Data – Download Data Dialog



Option to Approximate the Thru-Crack Out-of-Plane Bending Solution

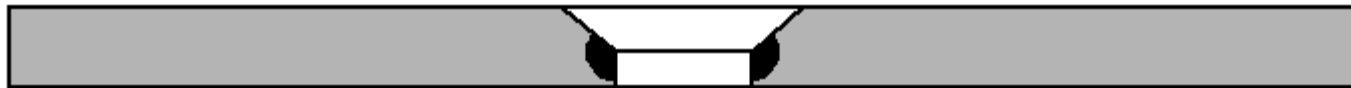
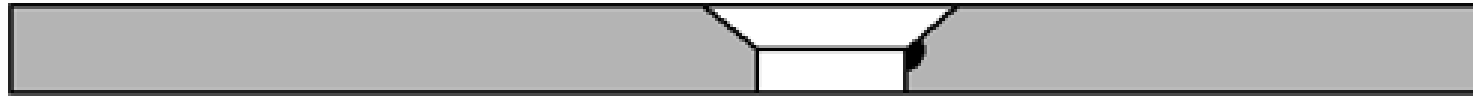


- Classic edge crack
- Classic double edge crack
- Classic through crack
- All advance cracks where bending was not available with the exception of crack at slot

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

Corner Crack at the Countersink Knuckle



Using different material data as a function of spectrum levels

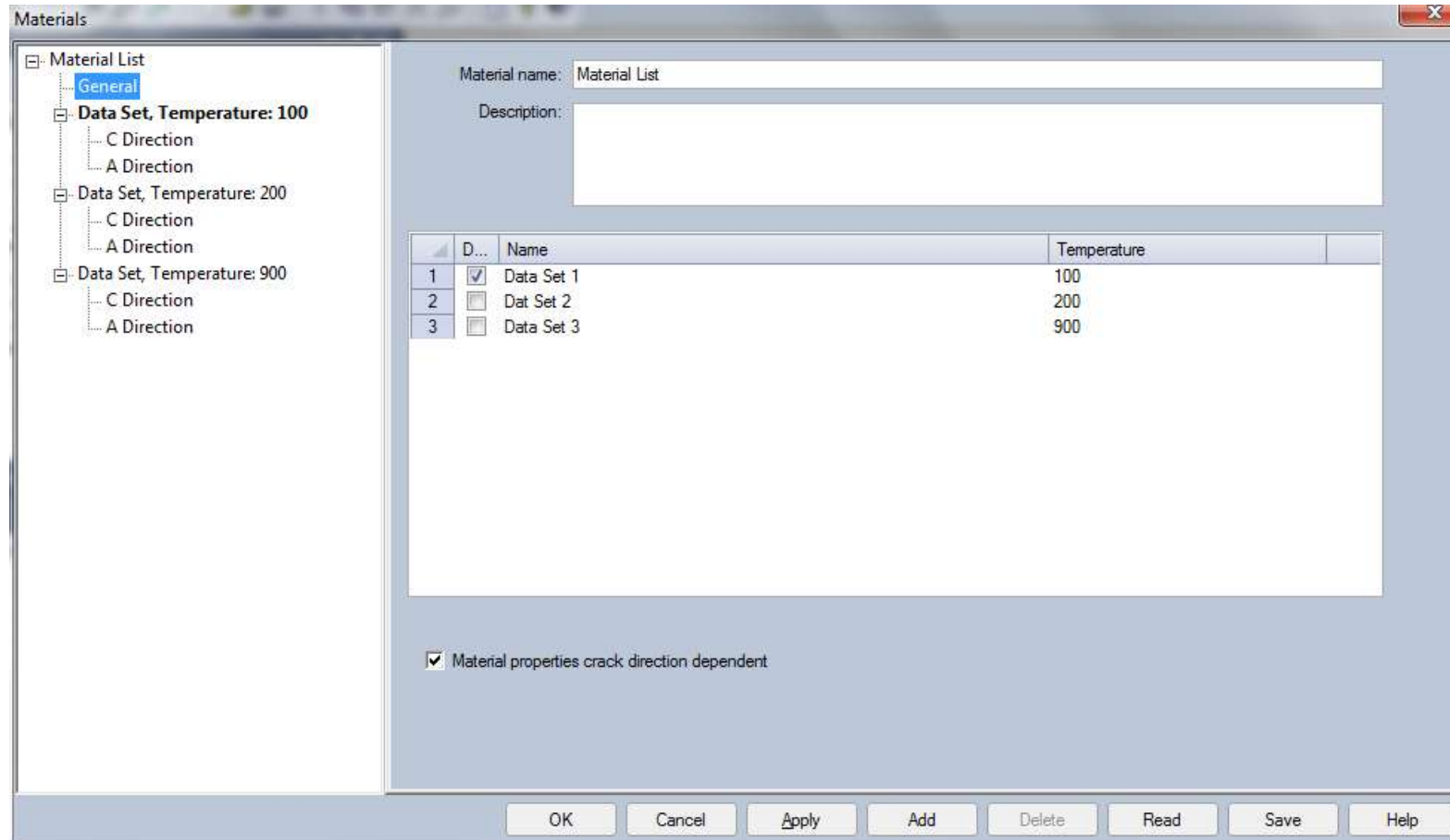
- Material data will consist of different material “sets”
- One material “set” is always default
- Material sets can be tagged for different conditions
- Only the Environment “tag” can be used right now
- Applicable only for tabular lookup data, but code infrastructure has been changed to handle any AFGROW material model if necessary, and requires only GUI changes
- Spectrum with Environment “tags” applied to a level
- 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

- 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” option
- DAX input file is backward and upward compatible
- Plugin model changed to handle different material data for different crack directions

New Tabular Look-Up Material Dialog Changes

General



New Material Dialog Changes

Material Set Property

Materials

Material List

- General
 - Data Set, Temperature: 100
 - C Direction
 - A Direction
 - Data Set, Temperature: 200
 - C Direction
 - A Direction
 - Data Set, Temperature: 900
 - C Direction
 - A Direction

Input values of Delta_K for da/dN values and up to 10 different R(stress ratio) values. Matrix must have at least two R values and two da/dN values. Input Delta_K for R >= 0, input Kmax for R < 0.0

Name: Data Set 1

Number of da/dn Sets: 27 Number of R Sets: 2

		R[1]	R[2]
		0.1	0.601
da/dN[1]	1.00e-009	2.606	1.38
da/dN[2]	3.00e-009	2.636	1.409
da/dN[3]	1.00e-008	2.673	1.503
da/dN[4]	2.00e-008	2.685	1.66
da/dN[5]	4.00e-008	2.729	1.897
da/dN[6]	6.00e-008	2.792	2.089
da/dN[7]	1.00e-007	2.954	2.355
da/dN[8]	2.00e-007	3.307	2.814
da/dN[9]	3.00e-007	3.605	3.133
da/dN[10]	4.00e-007	3.839	3.383
da/dN[11]	6.00e-007	4.209	3.744
da/dN[12]	1.00e-006	4.781	4.355
da/dN[13]	2.00e-006	5.696	5.218
da/dN[14]	4.00e-006	6.873	6.254
da/dN[15]	1.00e-005	8.825	8.014
da/dN[16]	2.00e-005	10.684	9.61

Ultimate Strength: 66

Young's Modulus: 10500

Coefficient of Thermal Expansion: 1.25e-005

Poisson's Ratio: 0.33

Upper limit on da/dN, DADNHI: 0.01

Lower limit on da/dN, DADNLO: 1e-009

Plane Stress Fracture Toughness, KC: 62.777

Plane Strain Fracture Toughness, KIC: 35

Delta K threshold value @R=0: 2.831

Yield Strength, YLD : 47

Lower limit on R shift (Max: 0): -0.3

Upper limit on R shift (0, 1): 0.63

OK Cancel Apply Add Delete Read Save Help

Using Different Material Data for Different Crack Directions

Materials

Material List

- General
- Data Set
 - C Direction
 - A Direction

Input values of Delta_K for da/dN values and up to 10 different R(stress ratio) values. Matrix must have at least two R values and two da/dN values. Input Delta_K for R >= 0, input Kmax for R < 0.0

Name: 7010-T73651 L-S Plt Lab Air

Number of da/dn Sets: 29 Number of R Sets: 2

		R[1]	R[2]
		0.1	0.3
da/dN[1]	1.00e-009	2.109	1.72
da/dN[2]	2.00e-009	2.122	1.733
da/dN[3]	1.00e-008	2.166	1.783
da/dN[4]	2.00e-008	2.284	1.895
da/dN[5]	4.00e-008	2.542	2.126
da/dN[6]	6.00e-008	2.75	2.305
da/dN[7]	1.00e-007	3.12	2.622
da/dN[8]	2.00e-007	4	3.368
da/dN[9]	3.00e-007	4.7	3.961
da/dN[10]	4.00e-007	5.2	4.382
da/dN[11]	6.00e-007	5.85	4.929
da/dN[12]	1.00e-006	6.4	5.391
da/dN[13]	2.00e-006	7.05	5.95
da/dN[14]	4.00e-006	8.2	6.9
da/dN[15]	1.00e-005	10.4	8.745
da/dN[16]	2.00e-005	13.3	11.172

Ultimate Strength: 72.5

Young's Modulus: 10000

Coefficient of Thermal Expansion: 1.31e-005

Poisson's Ratio: 0.33

Upper limit on da/dN, DADNHI: 0.1

Lower limit on da/dN, DADNLO: 1e-009

Plane Stress Fracture Toughness, KC: 62

Plane Strain Fracture Toughness, KIC: 25

Delta K threshold value @R=0: 2.299

Yield Strength, YLD: 63

Lower limit on R shift (Max: 0): -0.33

Upper limit on R shift (0, 1): 0.65

OK Cancel Apply Add Delete Read Save Help

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

Material Data from AFMAT Converted to Tabular Lookup Format in AFGROW

73 Materials Converted, 53 Approved

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 Pit & 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










AFMAT > Home

Online Crack Growth Database

	Id	Data Source	Condition Heat Treatment	Property Type	Alloy	Environment
<input type="checkbox"/> Alloy Steels	20280	Purdue Aging Aircraft Data		Fatigue Life (a vs N)	7075-T6	Unknown
<input type="checkbox"/> Aluminum	1222	AIR FORCE	A5 RECD	Plane Strain Fracture Toughness (K1C)	TI-6AL-4V	Unknown
<input type="checkbox"/> Beryllium/Beryllium Alloys	1223	Additional NASA Data	A5 RECD	Plane Strain Fracture Toughness (K1C)	TI-6AL-4V	Unknown
<input type="checkbox"/> Brass	1224	Additional NASA Data	A5 RECD	Plane Strain Fracture Toughness (K1C)	TI-6AL-4V	Unknown
<input type="checkbox"/> Bronze	1225	Additional NASA Data	A5 RECD	Plane Strain Fracture Toughness (K1C)	TI-6AL-4V	Unknown
<input type="checkbox"/> Copper/Copper Alloys	1226	Additional NASA Data	A5 RECD	Plane Strain Fracture Toughness (K1C)	TI-6AL-4V	Unknown
<input type="checkbox"/> Iron Alloys	1227	Additional NASA Data	A5 RECD	Fatigue Crack Growth Rate (da/dN vs delta K)	C11000(ETP BUS BAR)	LAB AIR
<input type="checkbox"/> Magnesium Alloys	1228	Additional NASA Data	A5 RECD	Fatigue Crack Growth Rate (da/dN vs delta K)	C11000(ETP BUS BAR)	LAB AIR
<input type="checkbox"/> Molybdenum/Molybdenum Alloys	1229	AIR FORCE	A5 RECD-PROBABLY MA	K1 Environmentally Assisted Cracking	TI-6AL-4V	3.5PCT NAACL
<input type="checkbox"/> Nickel Based Super Alloys	1230	NASA	A5 ROLL	Fatigue Crack Growth Rate (da/dN vs delta K)	304	LAB AIR

New Classic Models

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


Model	Description of the Configurations	Beta Solution
<input type="checkbox"/>	 Part Through Crack in Pipe	Application Defined
<input type="checkbox"/>	 Through Crack	User Defined
<input type="checkbox"/>	 Interdependent Through Cracks	User Defined
<input checked="" type="checkbox"/>	 Internal Through Crack	Application Defined
<input type="checkbox"/>	 Single Through Crack at Hole	Application Defined
<input type="checkbox"/>	 Double Through Crack at Hole	Application Defined
<input type="checkbox"/>	 Single Through Crack at a Semi-circular Notch	Application Defined
<input type="checkbox"/>	 Single Edge Through Crack	Application Defined
<input type="checkbox"/>	 Single Edge Through Crack in a Finite Height ...	Application Defined

Two inter-dependent through cracks model



Model Geometry/Dimension/Load Dialog

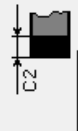
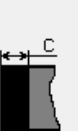
Geometry | Dimension | Load

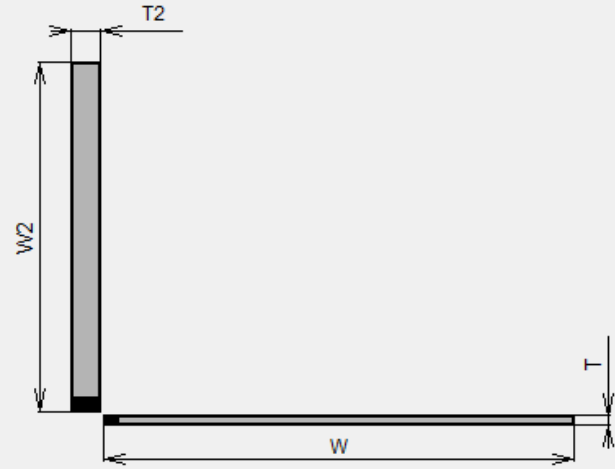
 Model dimensions are initialized to default values at start-up or when a new model configuration is selected.

Enter specimen dimensions

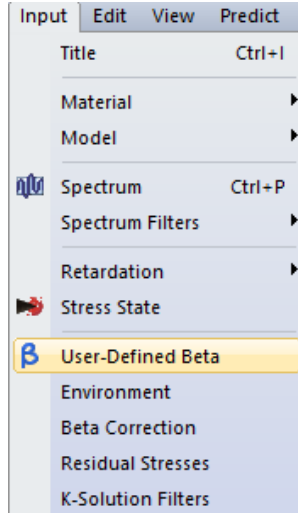
Width (W):	<input type="text" value="4"/>	Width 2 (W2):	<input type="text" value="3"/>
Thickness (T):	<input type="text" value="0.09"/>	Thickness 2 (T2):	<input type="text" value="0.25"/>

Enter crack dimensions

	Crack Length -'C' Direction:	<input type="text" value="0.15"/>
	Crack Length -'C2' Direction:	<input type="text" value="0.15"/>



User Defined Beta Dialog



Dialog

Enter 'C1' beta sets

Number of sets: 6

		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

Number of sets: 6

		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)

Corrosion Effects

- $d(\text{geometry})/d(\text{time})$ models: intergranular corrosion model or exfoliation corrosion modeling.
- Requires the time dependent spectrum in the old .st3 or new .spx format
- Only one of two can be used at the same time
- Initial crack size (pitting model): Pitting model is not time dependent, it calculates maximum possible pit size for a given environment/specified material
- Developed under contract with SAFE

Corrosion - Exfoliation

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

Exfoliation Material Loss

Material loss (damage) is modeled as a change in thickness (or equivalent dimensions for models without a thickness). This is quantified as shown below as a function of time (seconds) using the user-defined parameters: A', B and Humidity.

Enter

damage = $A \cdot t \cdot \exp(B \cdot RH)$
t - time

Note: the units for A' are length/seconds, and Humidity is expressed in decimal format.

Coefficient (A): 7.02034e-012

Coefficient (B): 6.44

Humidity % (RH): 0.56

OK Cancel

Corrosion - Intergranular

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

Intergranular Corrosion

Intergranular corrosion (damage) is modeled as a length from a user-defined initial defect size. It is quantified as a function of time (seconds) using the parameters: A and N as indicated below.

This is not used in crack growth predictions, but is reported in the output for reference purposes.

Enter

damage = $A t^n$
t - time

Note: the units for A are length/seconds

Coefficient (A): 8.60656e-008

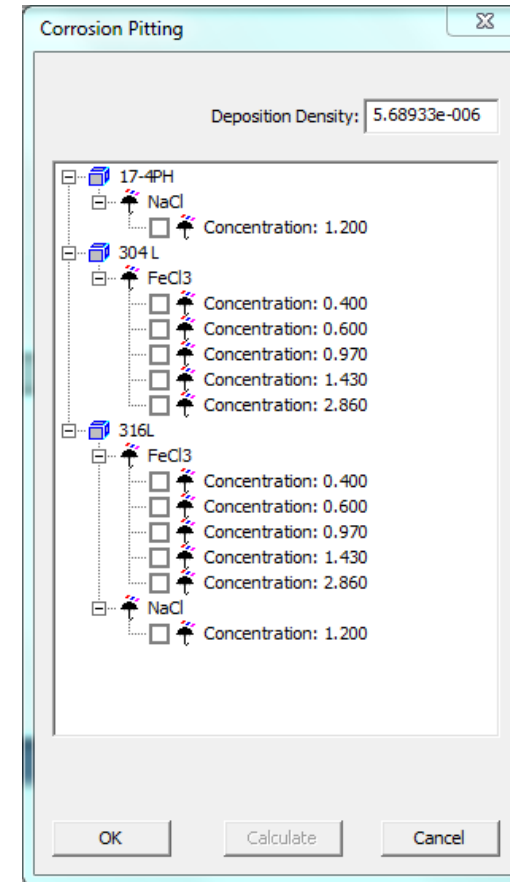
Coefficient (N): 0.5

Initial defect size: 0

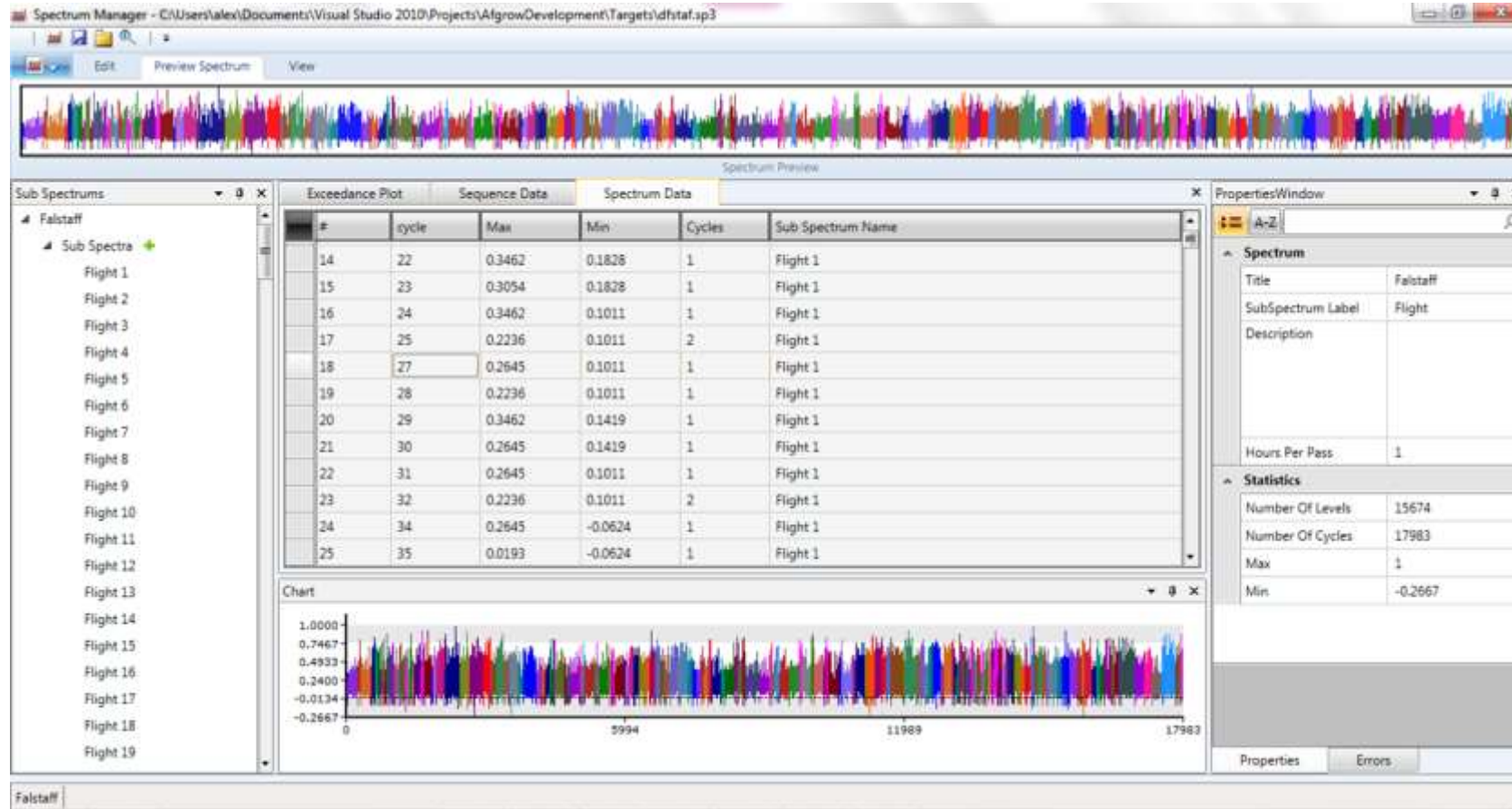
OK Cancel

Corrosion - Pitting

- This model predicts the maximum pit size possible for 17-4PH, 304L, and 316 stainless steel surfaces under thin film electrolyte conditions for the available test data and assumes a hemispherical pit.
- The maximum pit size possible is predicted by coupling the maximum cathode current (I_{cath}) available from the thin film electrolyte with the minimum current (I_{anode}) needed to grow a hemispherical pit. Users have the option to choose from five different concentrations for FeCl3 and one concentration for NaCl for the thin film conditions as indicated above
- The maximum pit size may be used to define an initial crack length for a subsequent life prediction. This will enable users to account for the total damage accumulated due to pitting corrosion for a given material and environmental conditions. The upper bound of the maximum pit radius is set to 0.0394 inches. This is believed to be the largest pit that one would ever expect to see on a surface



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
- Spectra normalization/de-normalization
- Clipping/Truncation capability
- Import data from “old” sub files

The screenshot shows a 'PropertiesWindow' with a search bar and a list of sub-spectra. The selected sub-spectrum is 'Flight 2'. Below it, there are sections for 'Statistics' and 'Tags'. The 'Statistics' section shows: Number Of Levels: 160, Number Of Cycles: 215, Max: 0.5505, Min: -0.1033. The 'Tags' section shows: Humidity: 100, Temperature: 120. At the bottom, there is a 'Name' field with the value 'Name of SubSpectrum'.

SubSpectrum	
Name	Flight 2
Description	

Statistics	
Number Of Levels	160
Number Of Cycles	215
Max	0.5505
Min	-0.1033

Tags	
Humidity	100
Temperature	120

Name
Name of SubSpectrum

Acknowledgements

- A-10 and T-38 Structural Integrity and Analysis Group
- SAFE Inc.
- NRC (compounding solution for two cracks under bearing load)
- ASIMIS
- AFGROW Customers and Consortium Members