AFGROW Workshop 2022

AFGROW Release 5.4 Overview

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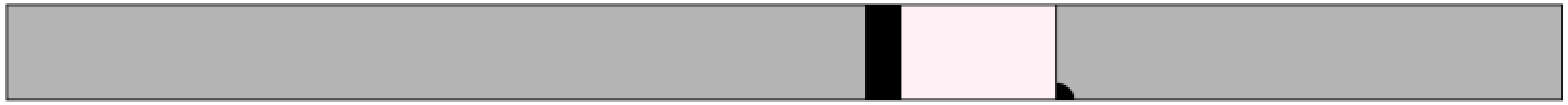
LexTech, Inc .

Release 5.04.01.25

- New/Enhanced Advanced Crack At Hole Solutions (combination of a corner crack and through crack at a hole)
- Multi-site Damage solutions
- New width correction for an advanced corner crack(s) at a hole
- New single and double through crack at a hole weight function solutions
- Local material database in tabular-lookup format
- 35 new crack initiation material data sets
- Option to open Tabular Lookup material data file through COM
- Modified output preferences: Add a check box to put output file in the same folder as input file. Allow the for each output file type to have the same name as an input file
- Option to use plugin from COM
- Better handling life in hours output. Output intervals printed in "hours" if the option to display life in hours is selected in the Output Intervals tab, the crack length plots are also converted to hours
- Print NASGRO material id in AFGROW output, save NASGRO model id in the AFGROW problem definition file
- Added Correction for a filled, unloaded hole for advanced models
- Added access to retardation metadata via Plug-in Interface
- Added prediction result information to AFGROW output XML file
- Implemented API 579 *Stress Intensity Factor Solutions for Cylinders* (22 new K models)
- Added CorLAS™ Burst Preassure Model
- Spectrum Manager is included in AFGROW installation

Combination of a Corner Crack and Through Crack at a Hole Solution

- Based on Börje Anderson SSHF2017 Database: *Straight Shank Hole with crack originating at Faying Surface*
- SSHF2017 Database contains only Corner Crack – Oblique Crack at Hole combination. The Corner Crack – Through Crack solution was generate by finding a limit value of K for the Oblique Crack, when its virtual A length goes to infinity
- Corner Crack – Through Crack solution can be used by itself or as a transition model from the Double Corner Cracks at Hole solution
- In the current AFGROW implementation, the solution parameters cover the following range:
  - $0.333 \le R/T \le 2$
  - $0.0 \le A1/T \le 0.95$
  - $0.1 \le A1/C1 \le 10$
  - $0.01 \le C1/C2 \le 6.0$

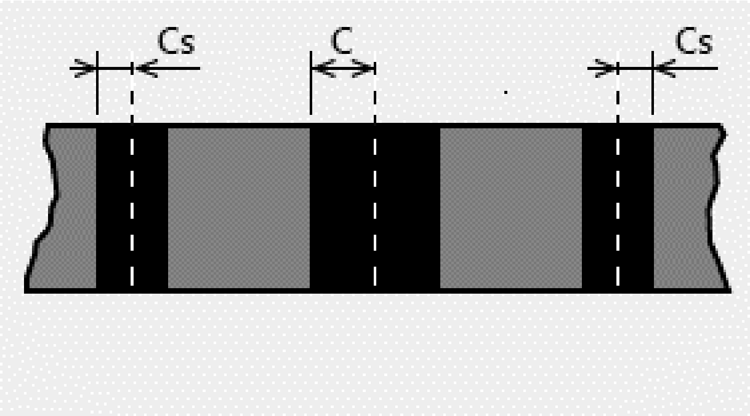


- R/T range will be extended to be between 0.1 and 10 in subsequent releases

Multisite Damage Solutions (MSD)

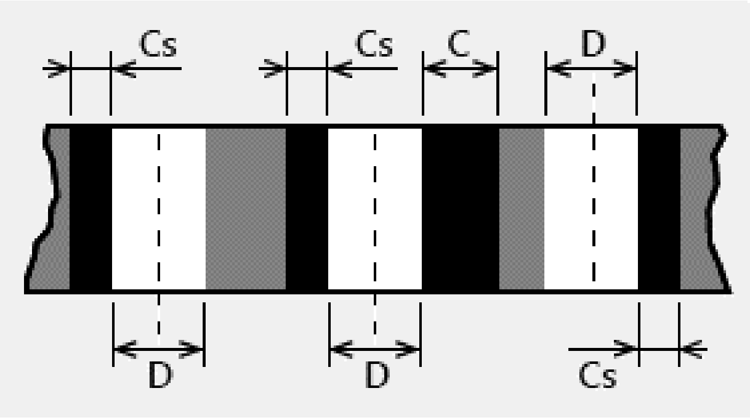
Multiple Through Cracks in an Infinite Plate

- Axial load case
- 3 to 9 cracks Multiple Holes in an Infinite Plate (Continuing Damage)



Axial and bearing load cases

- Primary and Secondary Crack at the Center Hole
- Single Secondary Crack on Outside of each adjacent hole (2, 4, 6, or 8 holes)



Multiple Holes in an Infinite Plate (Multisite Damage)

- Axial and bearing load cases
- Primary and Secondary Crack at the Center Hole
- Single Secondary Crack on Outside of each adjacent hole (2, 4, 6, or 8 holes)

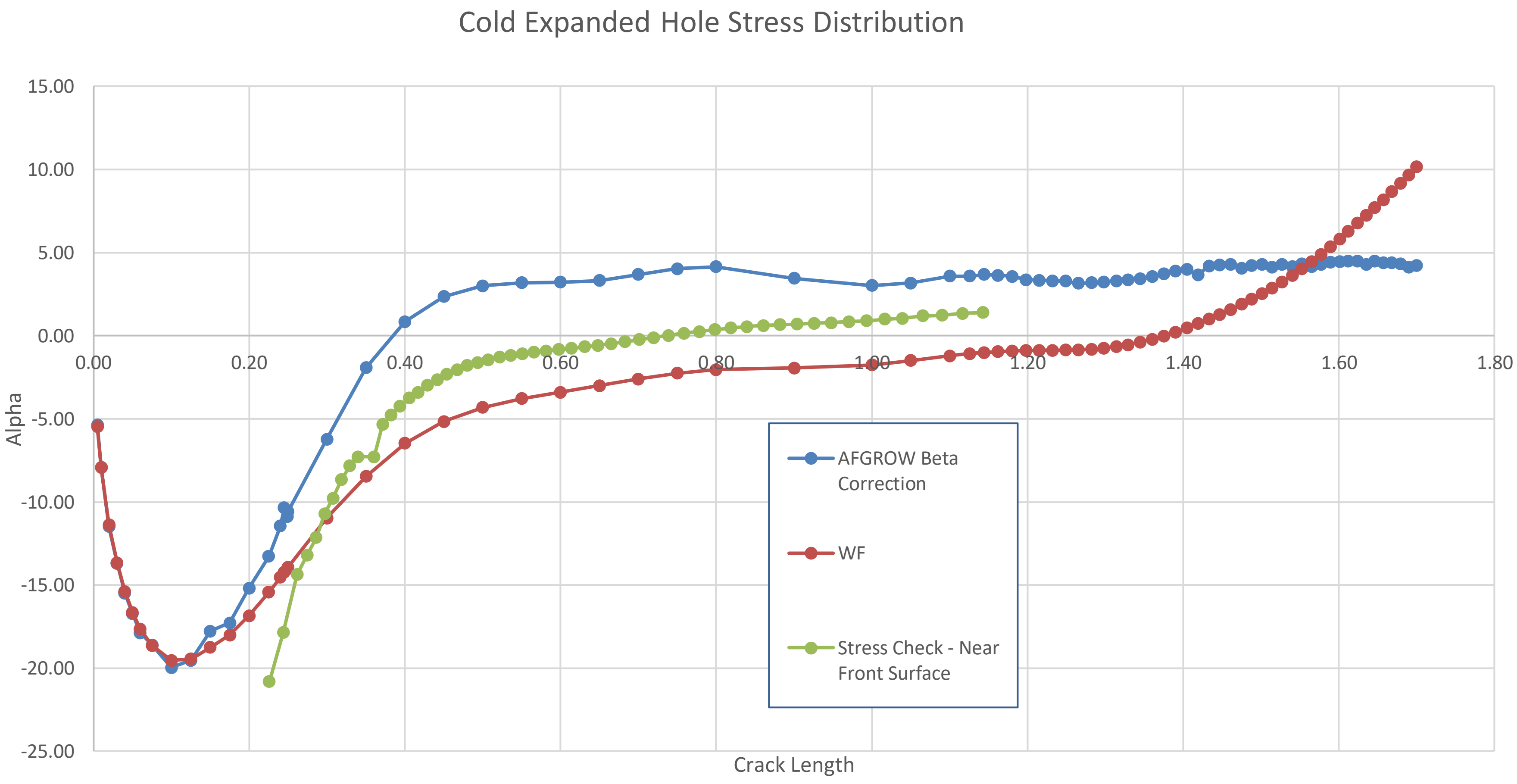
Width Correction for a Advanced Corner Crack(s) at a Hole Solution

- The through crack finite width correction is used as the baseline solution for all 3-D finite width corrections
- The 3-D width correction must converge to the 2-D correction as (a/t, a, & c) → 0 (both directions) and a/t → 1 (c-direction only)
- The Width Correction for a=c=0 is the unflawed Kt value for any W/D divided by 3
- AFGROW currently uses the 1986 Newman/Raju width correction (F_w) with a/t = 1 and a modification (F_{ww}) to correct it for W/D <= 6
- This has recently been reviewed, and a new correction has been developed
- We would like the correction to apply for W/D >= 1.5
- Thanks to Adrian Loghin and Scott Prost-Domasky for all of their help with FE validation solutions

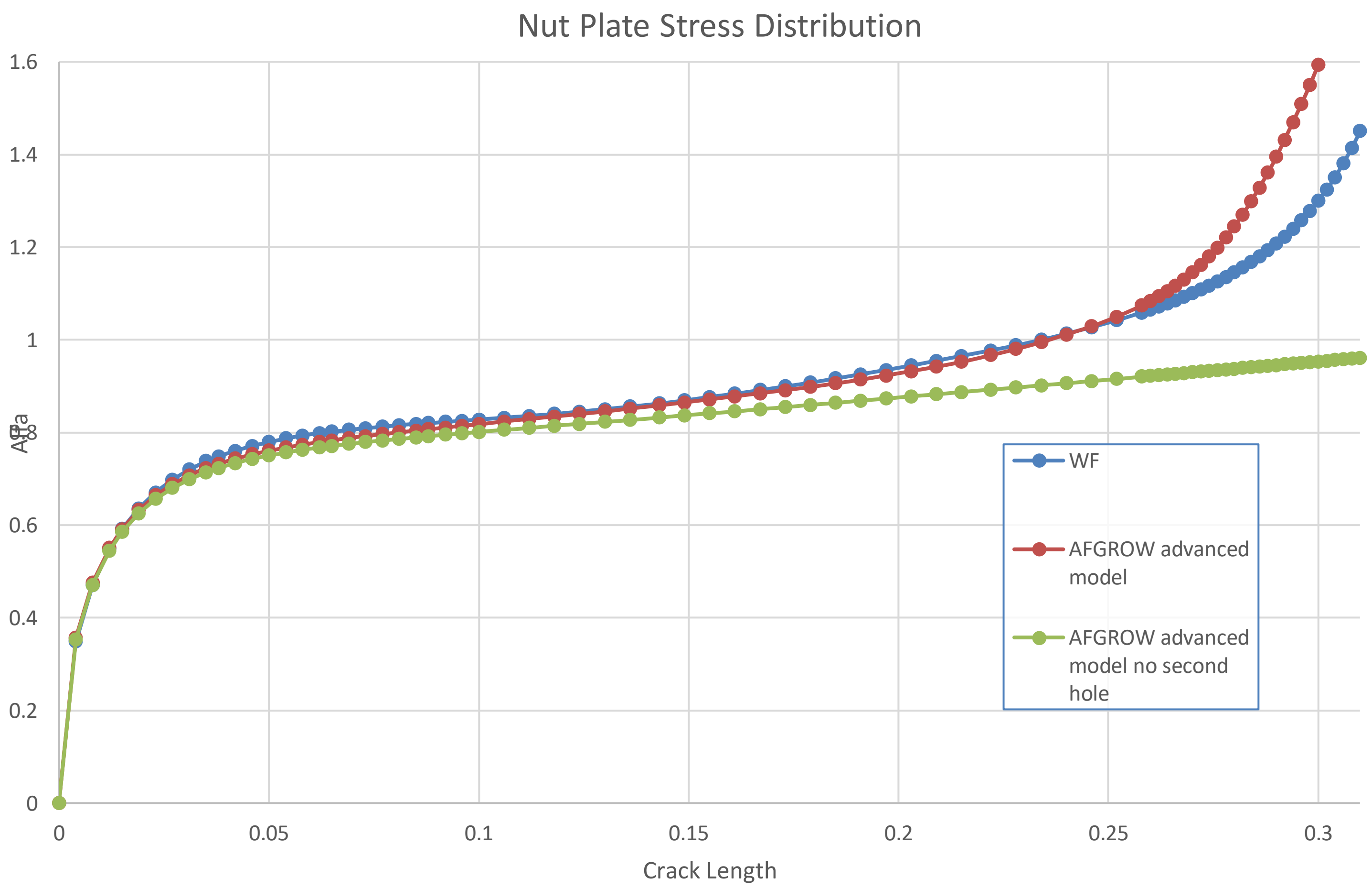
Single and Double Through Crack at Hole Weight function Solutions

Based on Jihwi Kim, Michael R. Hill (*Department of Mechanical and Aerospace Engineering, University of California*) paper: "*Weight functions for a finite width plate with single or double radial cracks at a circular hole*" that was published in Engineering Fracture Mechanics and also presented at AFGROW Workshop 2016

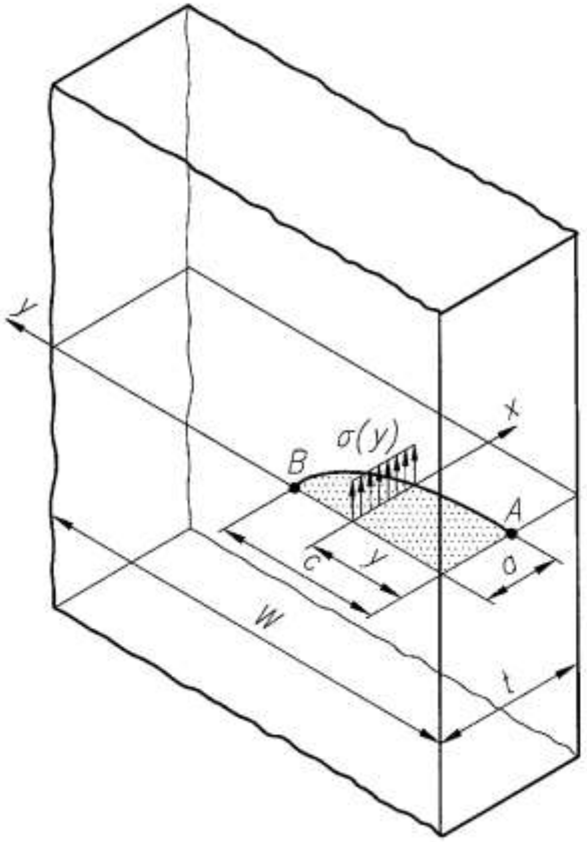
Single Through Crack at a Hole Weight Function Solution Verification - Case 1



Single Through Crack at Hole Weight Function Solution Verification - Case 2



Single Edge Corner Crack Weight Function Solution

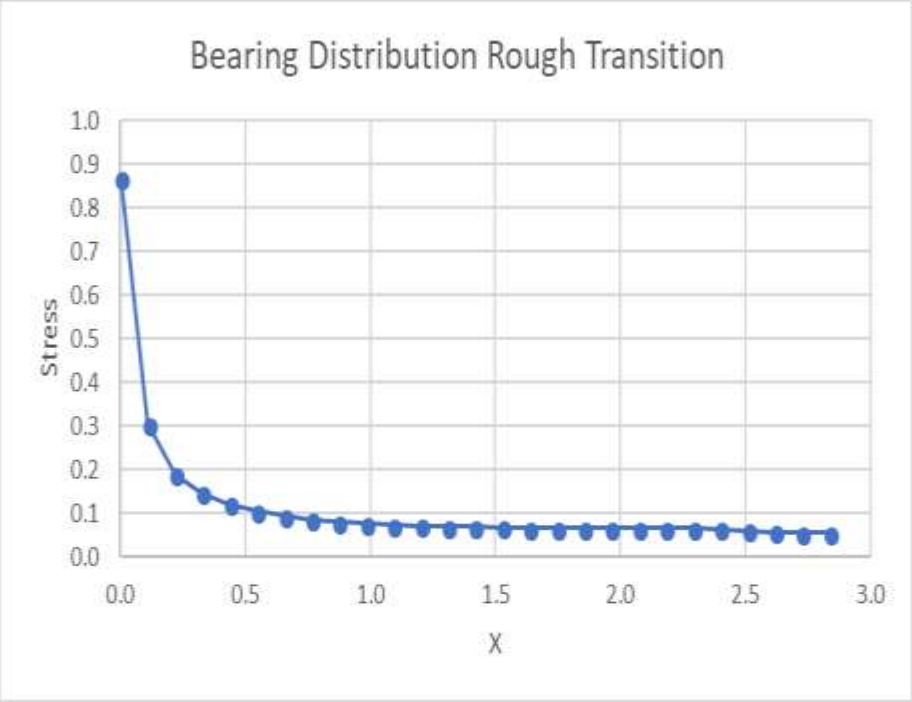


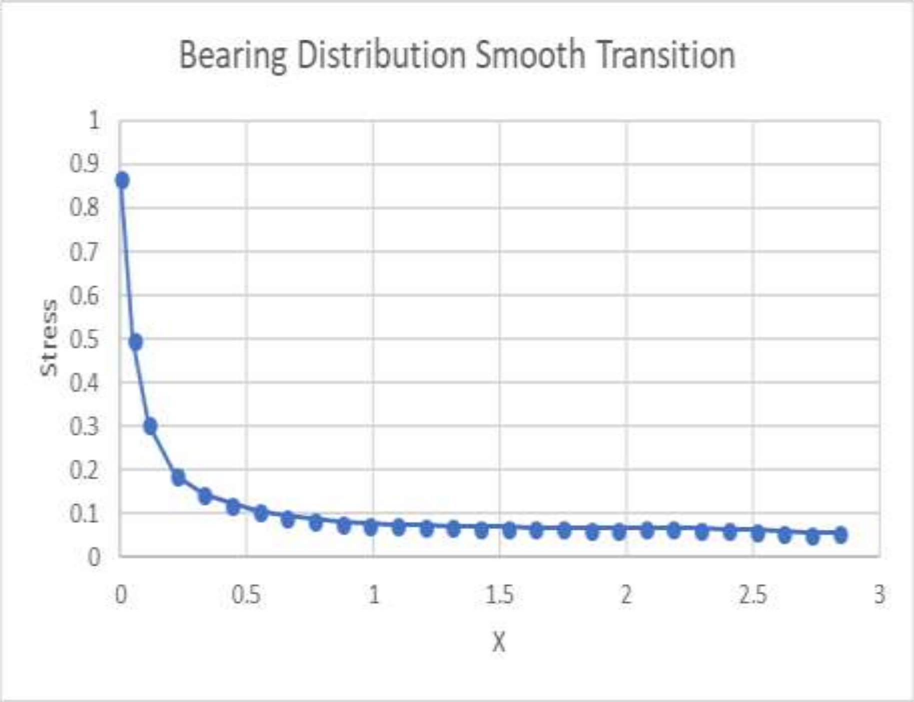
Based on Glinka, G., PhD, DSc., "*Quarter-elliptical corner crack in a finite thickness plate – in plane stress distribution*" delivered to LexTech, Inc. as part of the contract with SAFFD, Inc., Mannheim, Ontario, Canada

Can be used to model the single edge corner crack or single corner crack at hole

Single Edge Corner Crack Weight Function Solution Validation: Bearing Load Stress Distribution

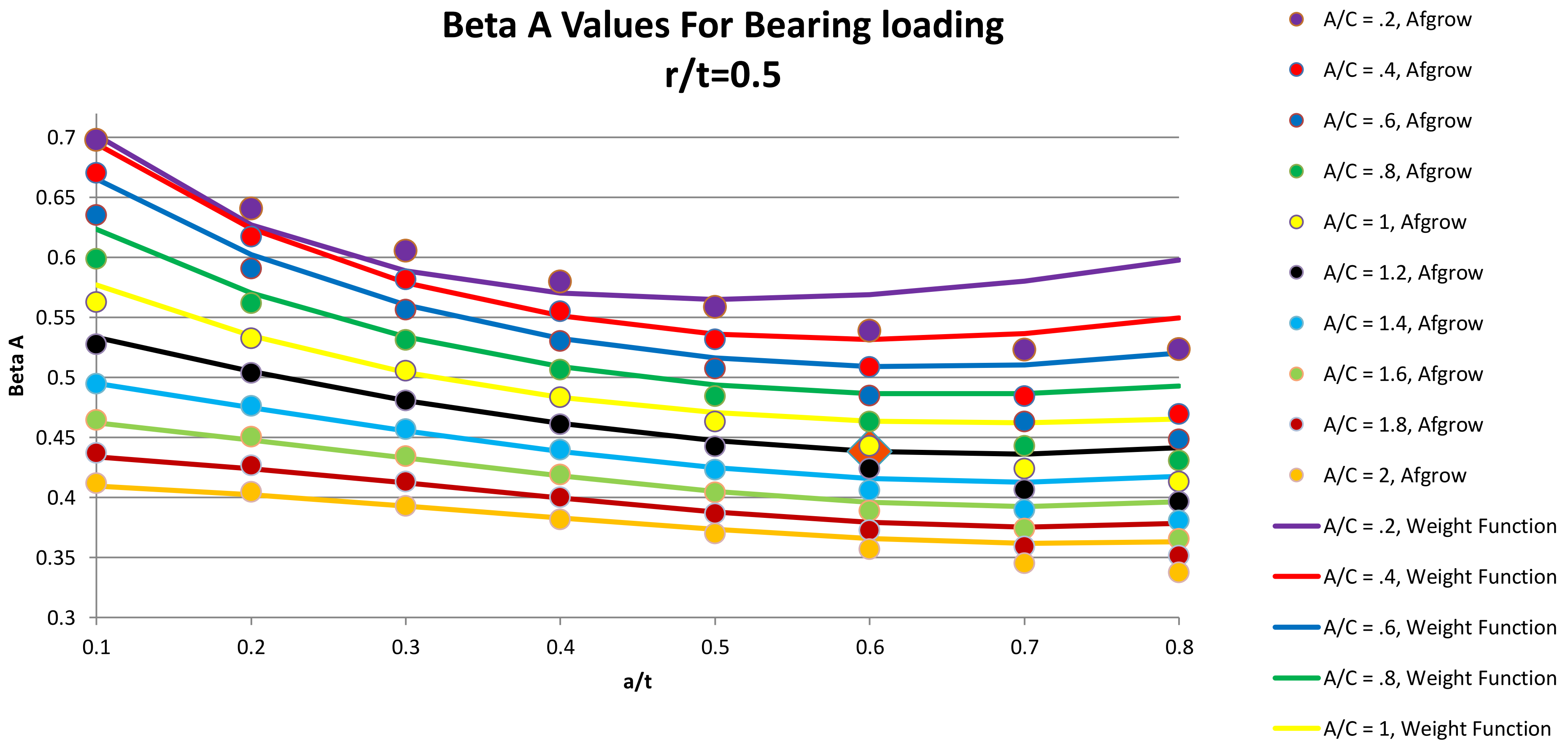
A plate with a centered hole, under bearing loading with a diameter equal to 0.629922 inches and a width of 6.299216 inches was used to produce the stress distribution. The generated betas were compared to advanced single corner crack at hole solution in AFGROW.





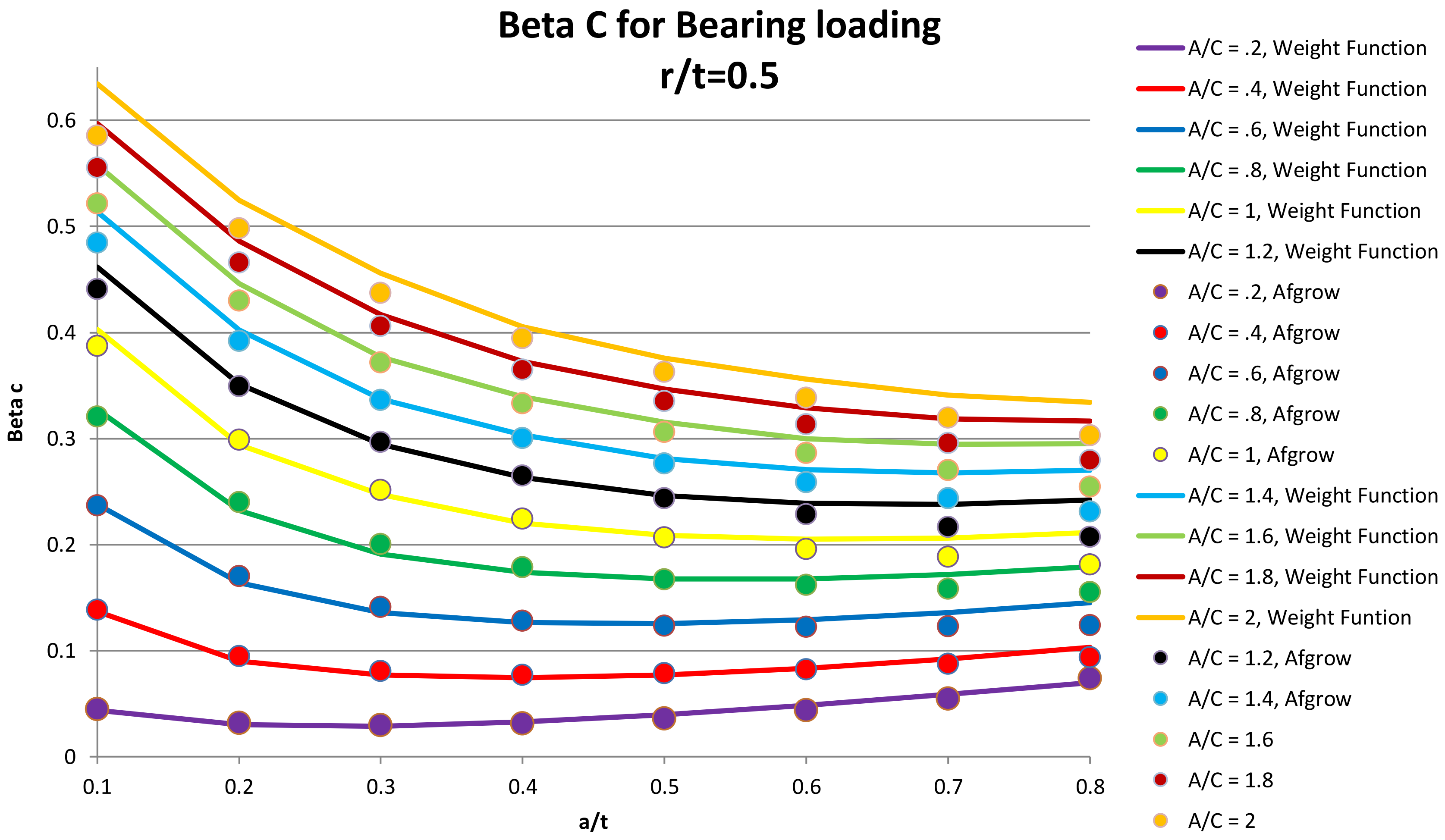
The stress distribution on the left was initially used to calculate the SIF and the results were not as expected.
An additional point was added to the beginning of the plot to smooth the transition. This change significantly improved the results.

Single Edge Corner Crack Weight Function Solution Verification: Bearing Load Stress Distribution Results



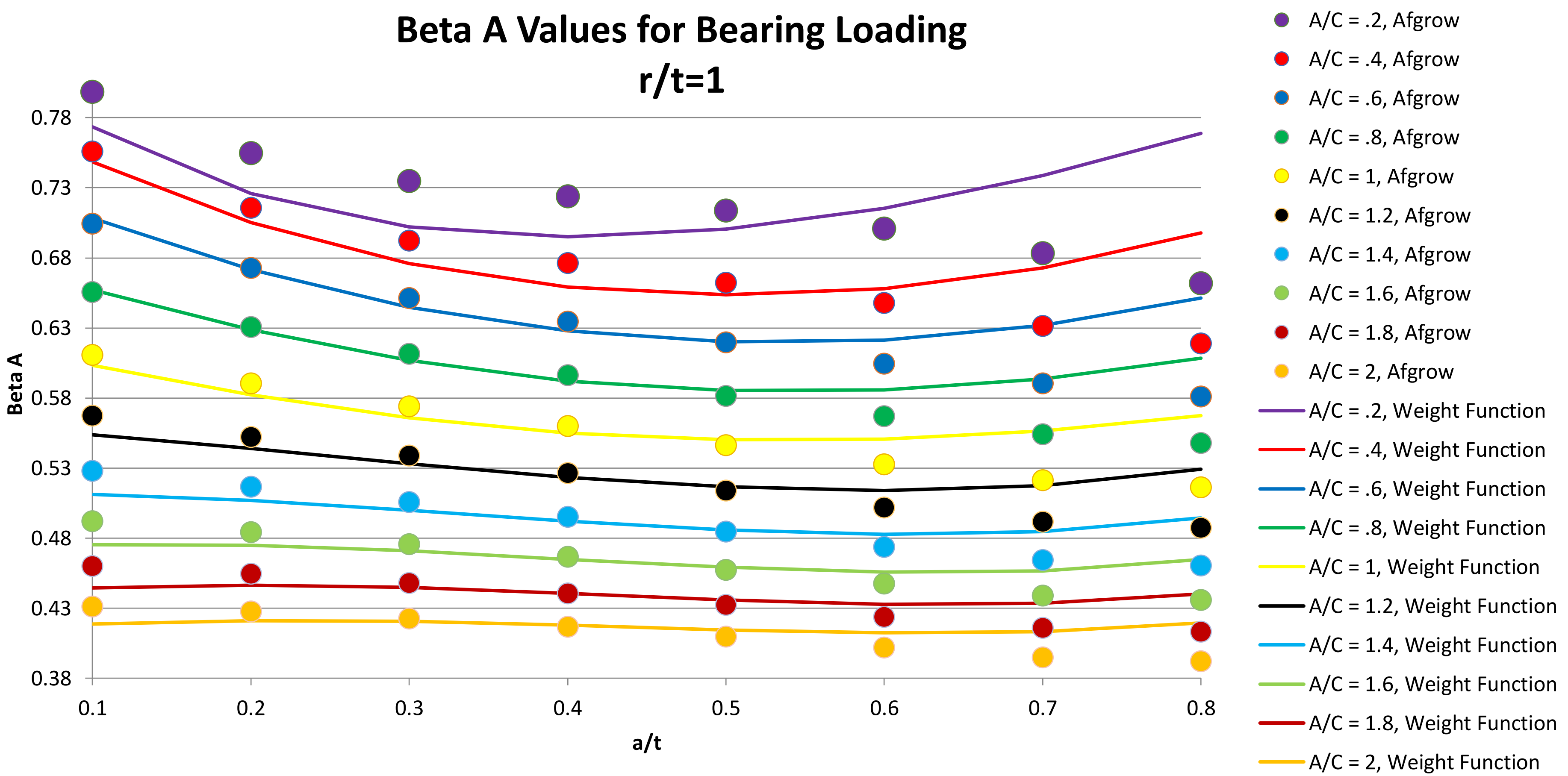
For the majority of the WF generated beta the error does not exceeds 2%. The error growth beyond 2% at a/t =0.7 and above.

Single Edge Corner Crack Weight Function Solution Verification: Bearing Load Stress Distribution Results



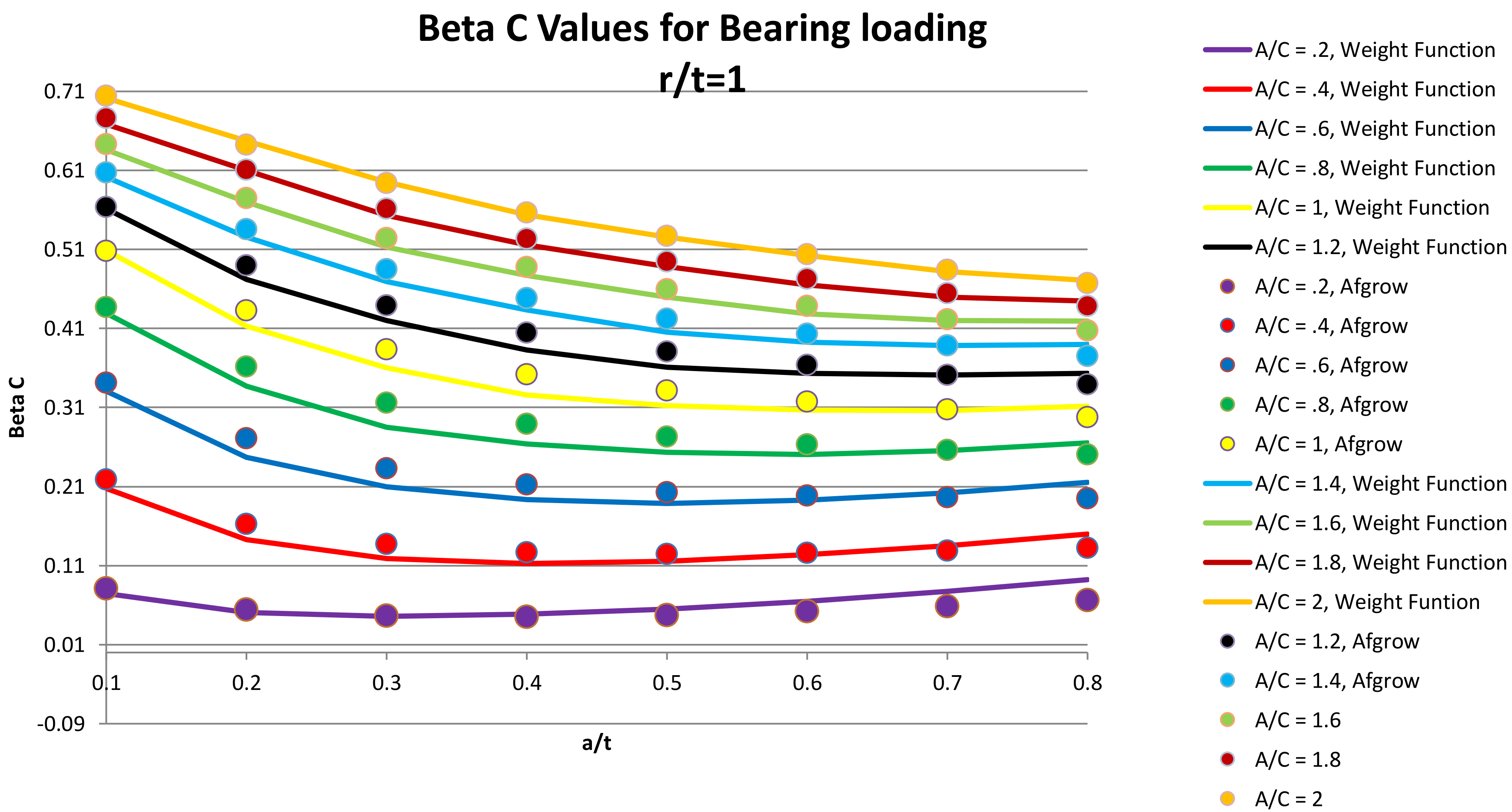
For the majority of the WF generated beta the error does not exceeds 5%. The error growth beyond 5% at a/t =0.7 and above.

Single Edge Corner Crack Weight Function Solution Verification: Bearing Load Stress Distribution Results



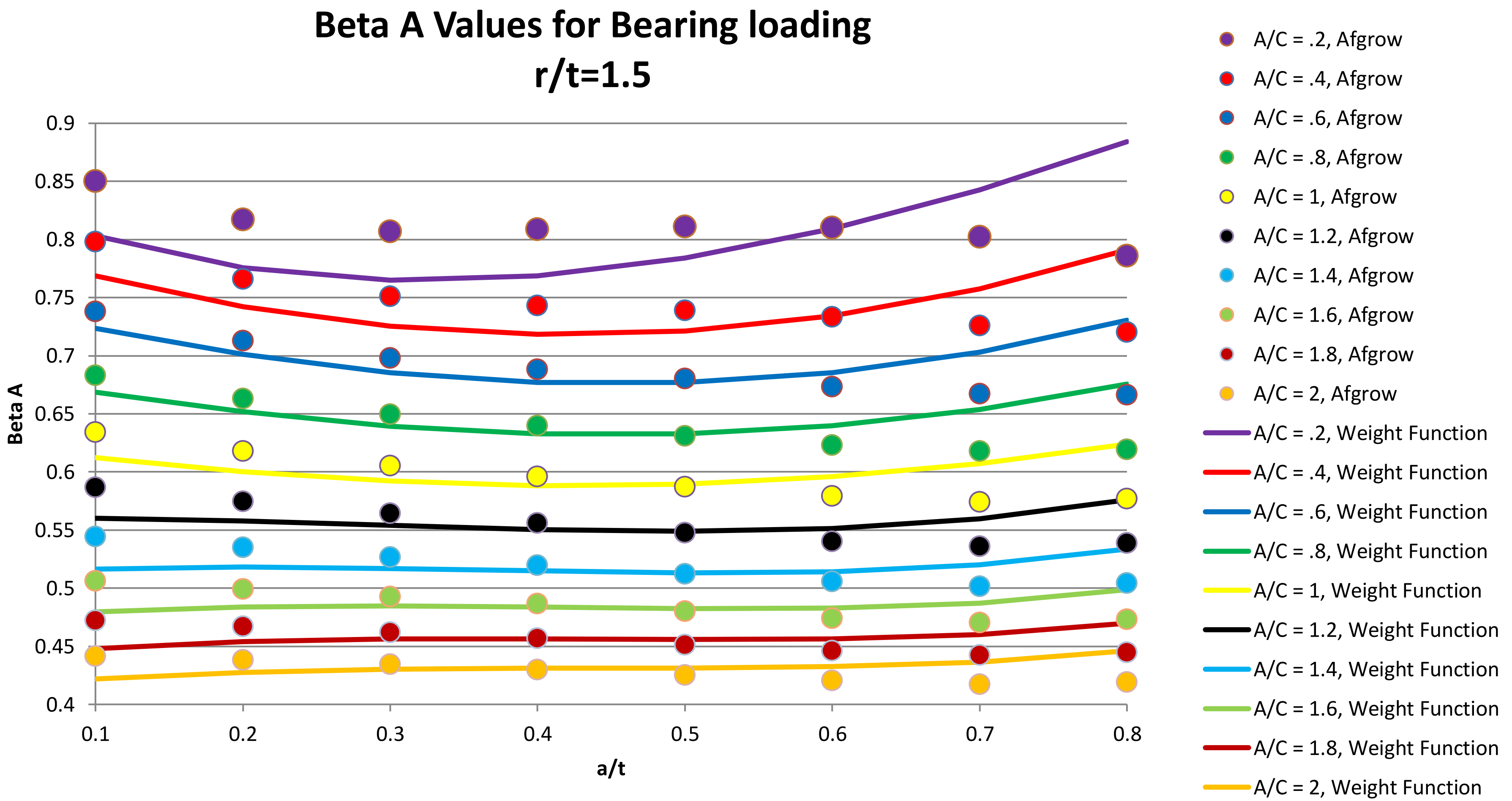
For the majority of the WF generated beta the error does not exceeds 8%. The error growth beyond 8% at a/t =0.7 and above.

Single Edge Corner Crack Weight Function Solution Verification: Bearing Load Stress Distribution Results



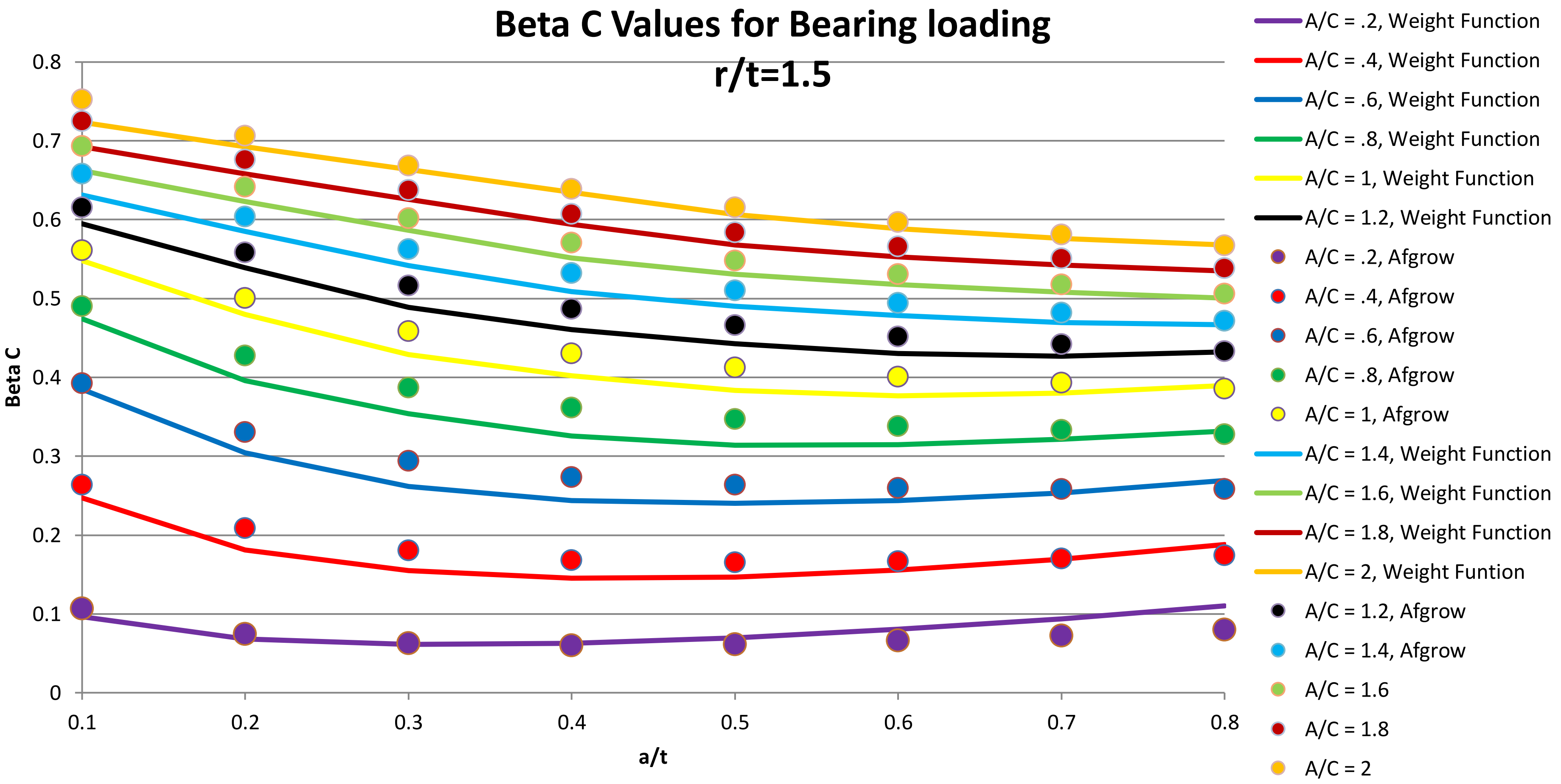
For the majority of the WF generated beta the error does not exceeds 3.7%. The error growth beyond 3.7% at a/t =0.7 and above.

Single Edge Corner Crack Weight Function Solution Verification: Bearing Load Stress Distribution Results



For the majority of the WF generated beta the error does not exceeds 6%. The error growth beyond 6% at a/t =0.7 and above.

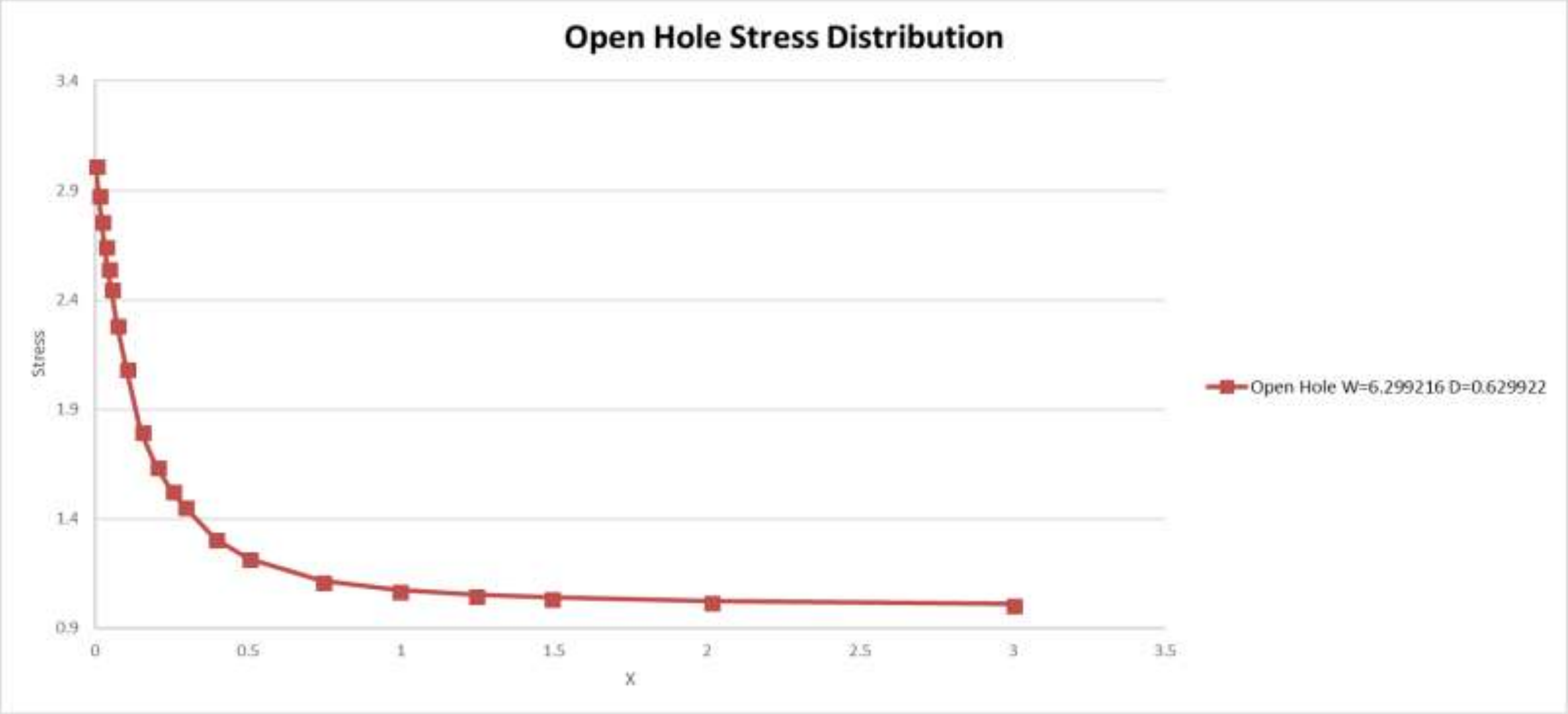
Single Edge Corner Crack Weight Function Solution Verification: Bearing Load Stress Distribution Results



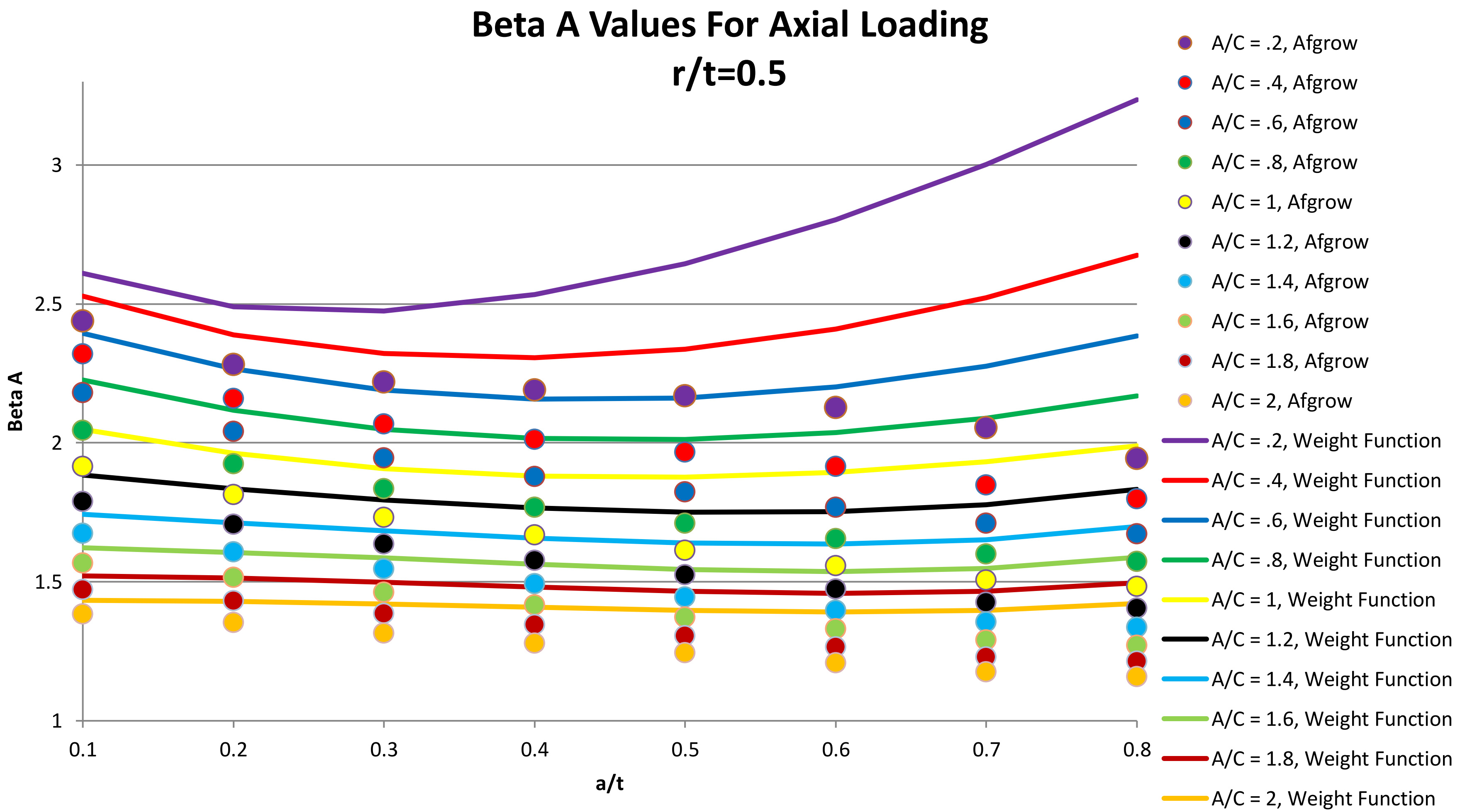
For the majority of the WF generated beta the error does not exceeds 5%. The error growth beyond 5% at a/t =0.7 and above.

Single Edge Corner Crack Weight Function Solution Validation: Axial Load Stress Distribution

A plate with a centered hole, under bearing loading with a diameter equal to 0.629922 inches and a width of 6.299216 inches was used to produce the stress distribution. The generated betas were compared to advanced single corner crack at hole solution in AFGROW.

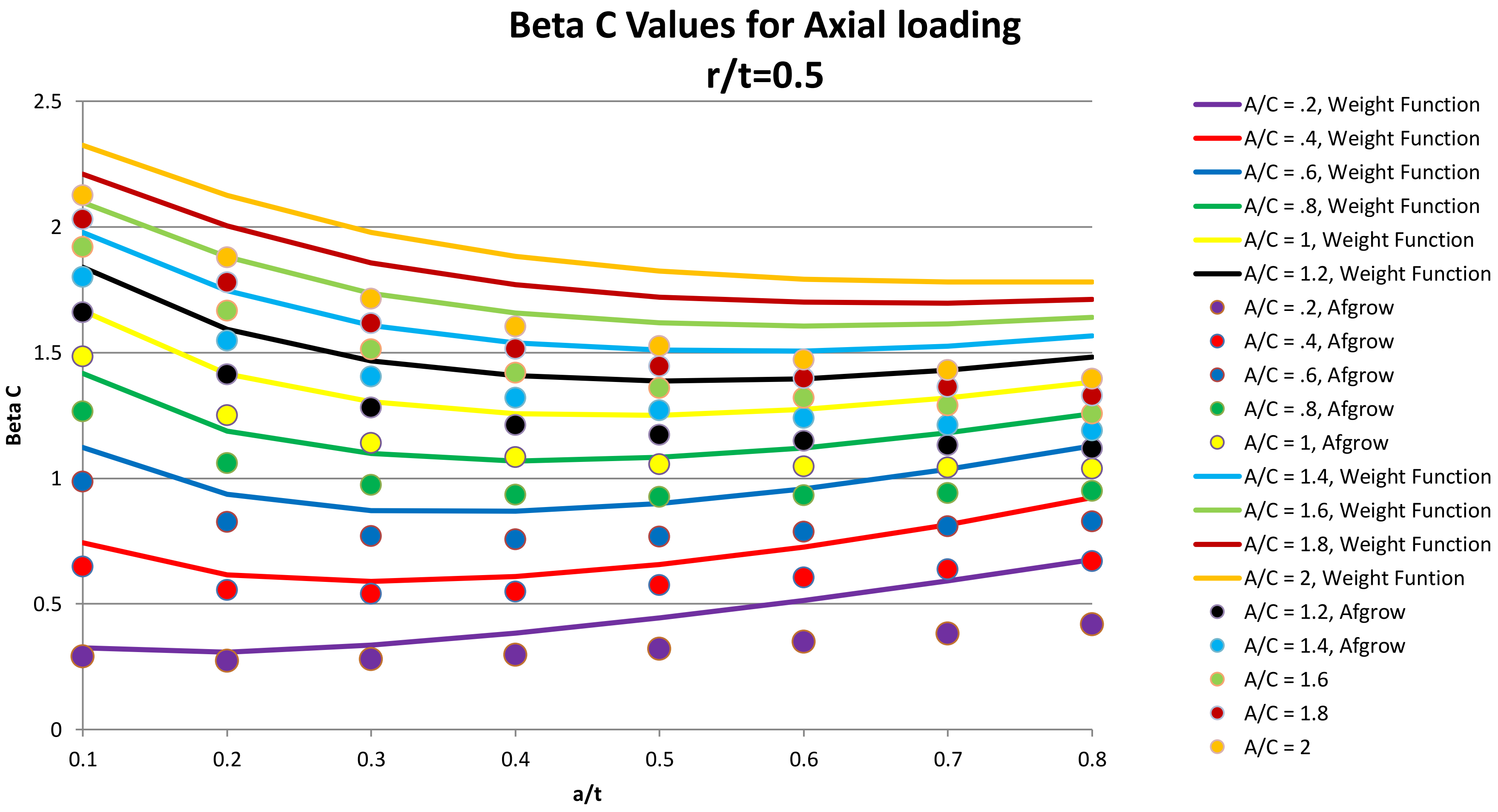


Single Edge Corner Crack Weight Function Solution Verification: Axial Load Stress Distribution Results



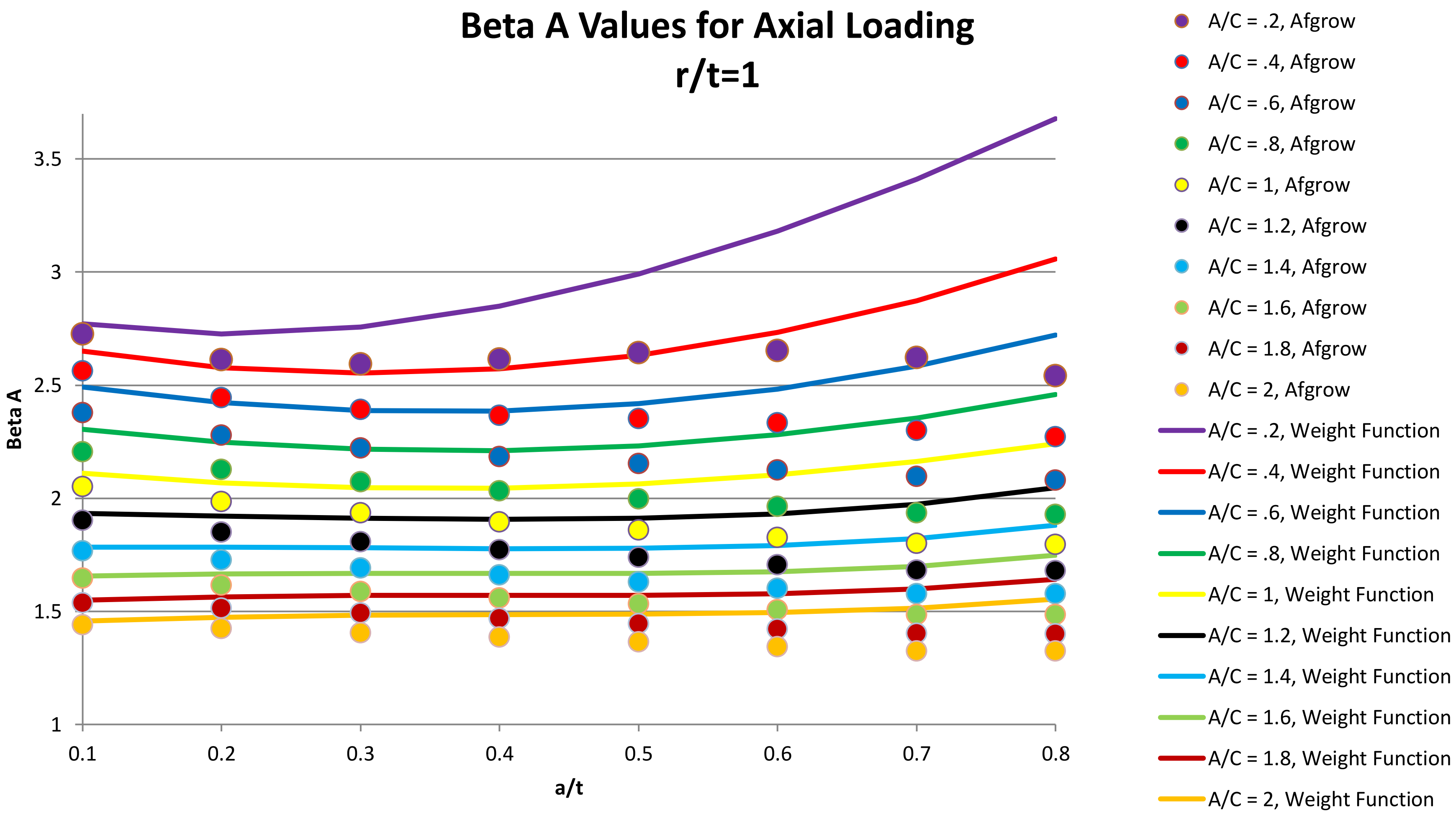
For the majority of the WF generated beta the error does not exceeds 15%. The error growth beyond 15% at a/t =0.5 and above.

Single Edge Corner Crack Weight Function Solution Verification: Axial Load Stress Distribution Results



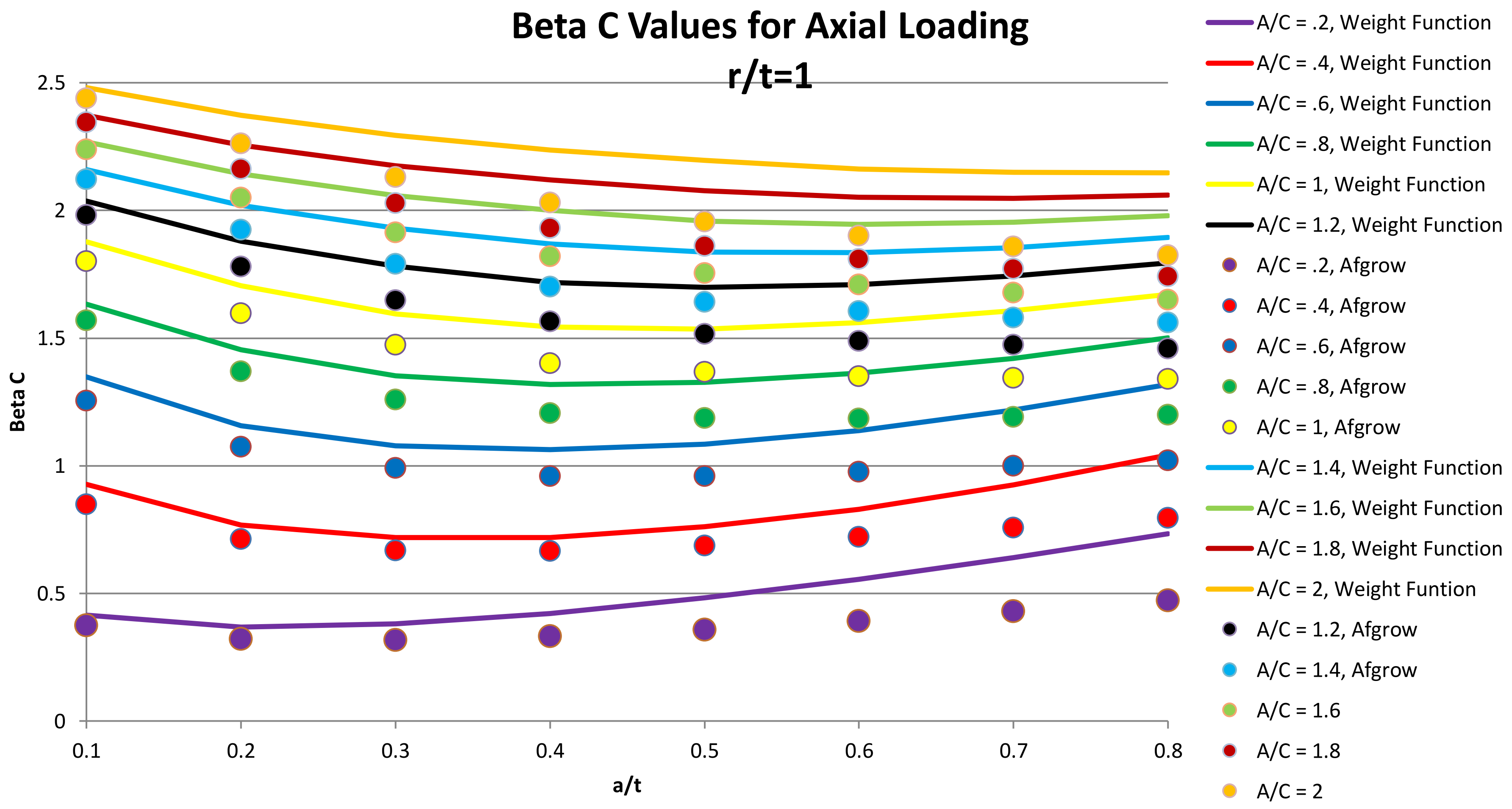
For the majority of the WF generated beta the error does not exceeds 11%. The error growth beyond 11% at a/t =0.5 and above.

Single Edge Corner Crack Weight Function Solution Verification: Axial Load Stress Distribution Results



For the majority of the WF generated beta the error does not exceeds 10%. The error growth beyond 10% at a/t =0.6 and above.

Single Edge Corner Crack Weight Function Solution Verification: Axial Load Stress Distribution Results



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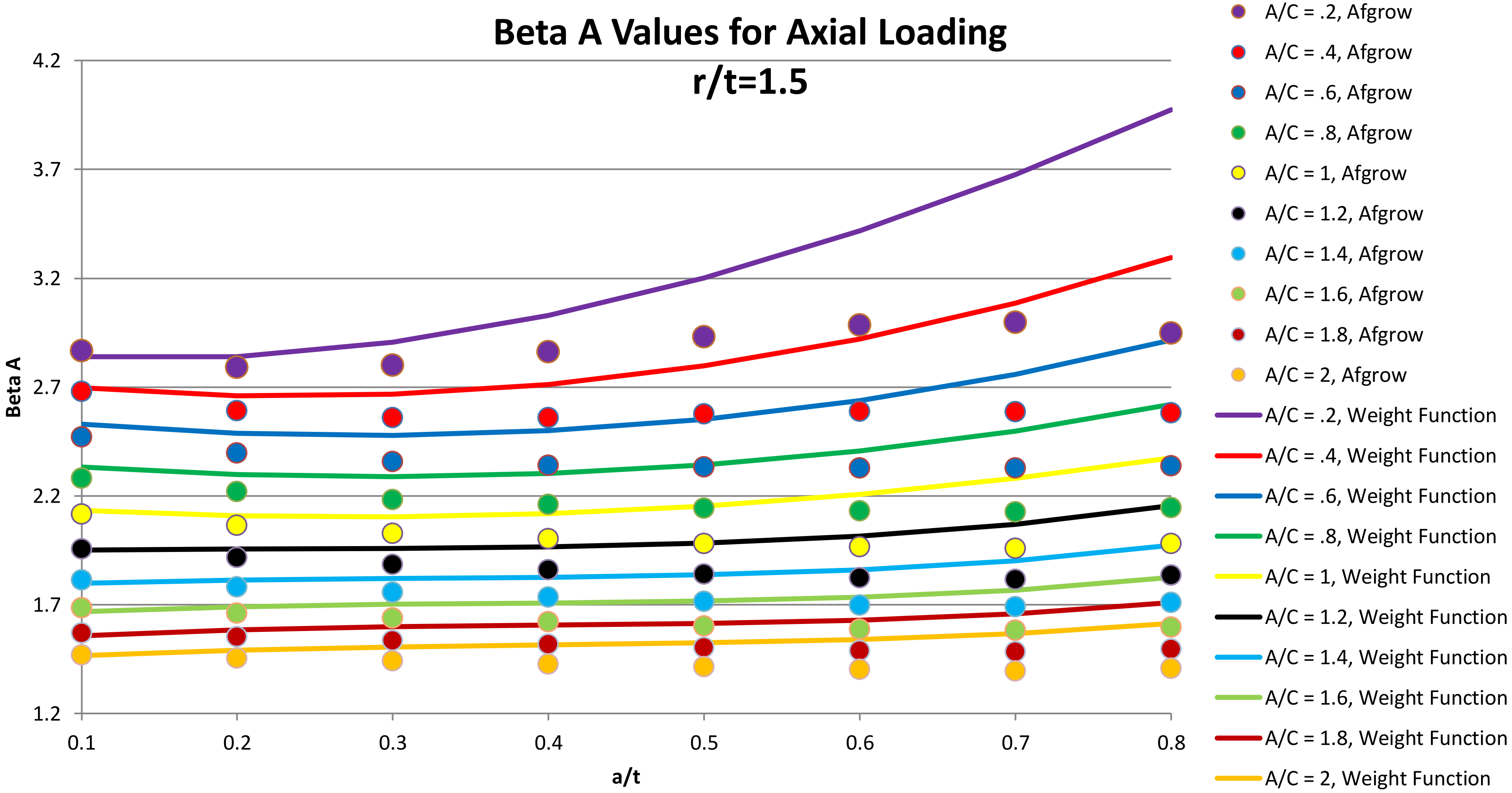
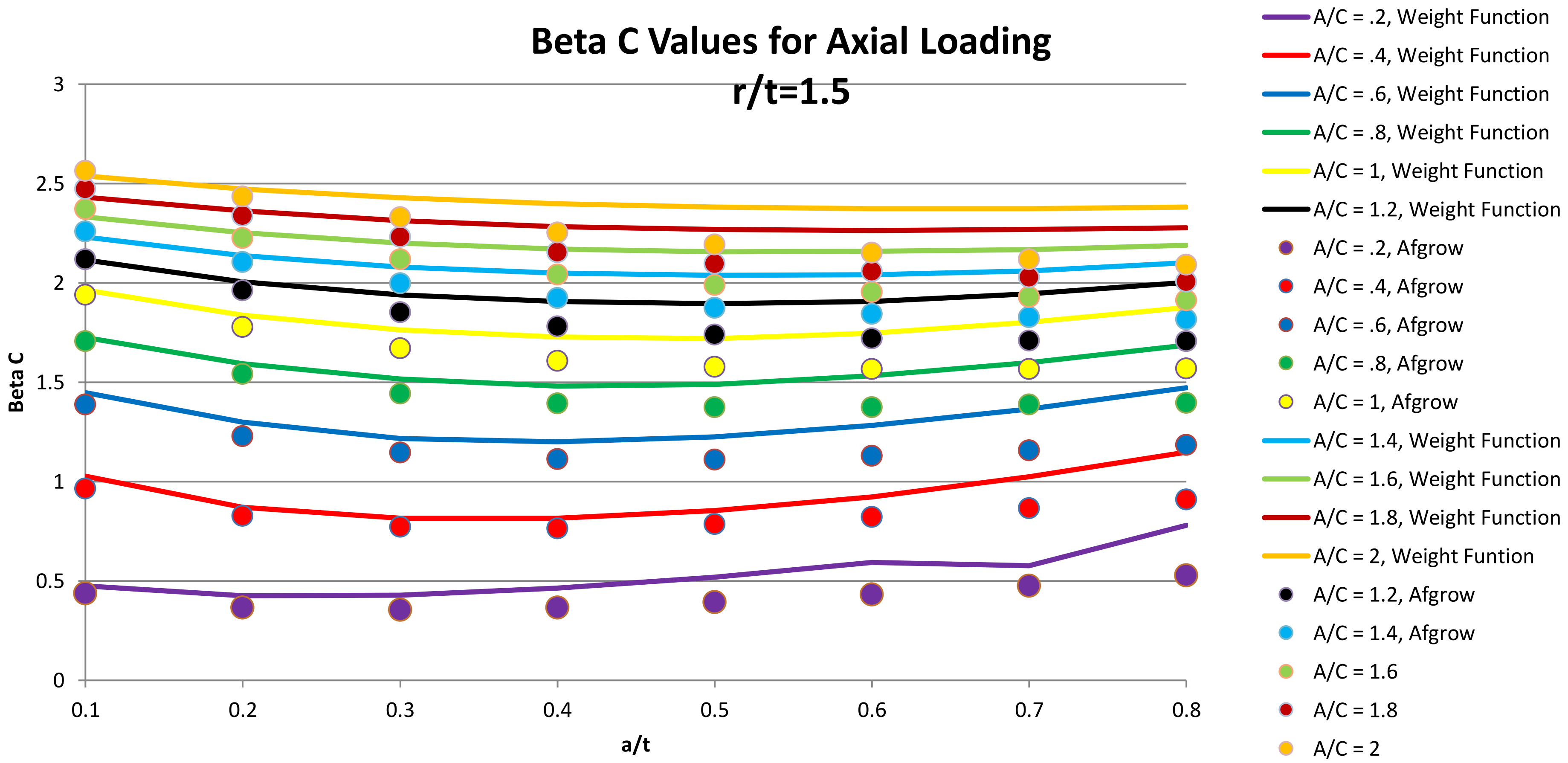
Single Edge Corner Crack Weight Function Solution Verification: Axial Load Stress Distribution Results



For the majority of the WF generated beta the error does not exceeds 15%. The error growth beyond 15% at a/t =0.6 and above.

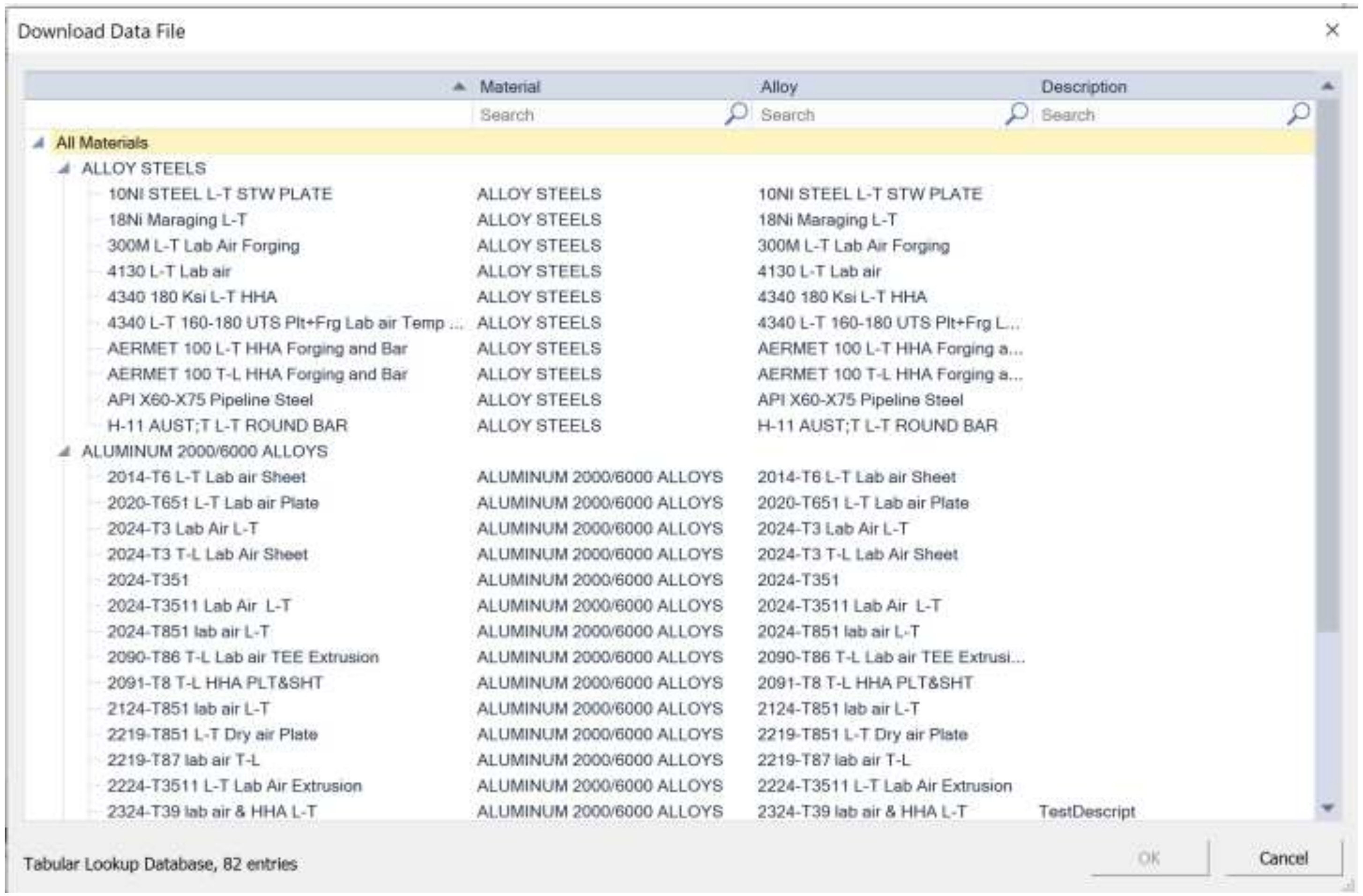
Single Edge Corner Crack Weight Function Solution Verification: Axial Load Stress Distribution Results



For the majority of the WF generated beta the error does not exceeds 6%. The error growth beyond 7% at a/t =0.6 and above.

Local Material Database in the Tabular-Lookup format

- Based on AFMAT Raw Data
- Searchable by material name and material type
- Data can not be modified
- AFGROW can be configured to be used the database on local computer, network server or company intranet
- There are currently tabular curve fits for 85 materials in the database are available



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New Crack Initiation Material Parameter Data

Material Browser

Material	Hardness(a)	Product Condition(b)	UTS, MPa	TYS,MPa	cfs, Mpa	RA, %	EL, %	E, GPa	n'	K', MPa	SIGF', MPa	b	EPSF'	c
All Materials														
ALLOY STEELS														
SAE 950-120	120 HB	As-received	440	375	960	66		204	0.158	875	811.6	-0.095	1.027	-0.63
SAE 950-150	150 HB	As-received	539	385	1000	64		204	0.16	1000	825	-0.08	0.425	-0.55
SAE 950-180	180 HB	As-received	575	450	1150	70		204	0.175	1500	1000	-0.08	0.25	-0.45
SAE 980-160	160 HB	As-received	637	560	1200	64		206	0.15	1300	1200	-0.105	2.5	-0.8
SAE 980-200	200 HB	As-received	675	585	1325	68		206	0.155	1350	1150	-0.09	1.25	-0.7
SAE 980-225	225 HB	As-received	699	595	1250	67		206	0.16	1400	1170	-0.085	1.25	-0.72
SAE-AISA 1035 Steel		Hot-rolled	476	250	751	56		196	0.24	1185	906	-0.11	0.33	-0.47
SAE-AISA 1035 Steel		Quenched & Tempered	1900	1450	2172	40		200	0.15	2500	3690	-0.13	0.2	-0.63
SAE-AISI 1005 Steel		Hot-rolled	338	230	907	77		207	0.255	1152	802	-0.135	0.37	-0.52
SAE-AISI 1006 Steel	85HB	Hot-rolled	318	248		73		207	0.243	1064	775	-0.125	0.607	-0.53
SAE-AISI 1015 Steel	80HB	Normalized	415	227	725	68		206	0.24	1058	976	-0.14	0.76	-0.59
SAE-AISI 1025 Steel		Hot-rolled	555	345	1035	60		205	0.195	1130	957	-0.095	0.45	-0.5
SAE-AISI 1030 Steel	128HB	Hot-rolled	454	289	764	59		206	0.28	1410	735	-0.105	0.1	-0.35
SAE-AISI 1045 Steel		Hot-rolled	671	327	1061	44		216	0.22	1402	1099	-0.11	0.52	-0.54
SAE-AISI 1045 Steel	500HB	Quencehed & Temper...	1825	1688	2273	51		206	0.12	2650	2165	-0.08	0.22	-0.66
SAE-AISI 1045 Steel	225HB	Annealed	751	516	998	44		203	0.17	1178	960	-0.08	0.5	-0.52
SAE-AISI 1080 Steel	371/410HB	Quenched & Tempered	1365	1189	1698	32		204	0.145	2052	1860	-0.09	0.65	-0.62
SAE-AISI 1080 Steel	421HB	Austempered	1349	978	1645	32		204	0.21	3177	2364	-0.1	0.51	-0.59
SAE-AISI 4130 Steel	362/371HB	Quenched & Tempered	1426	1357	1819	54		199	0.13	1837	1731	-0.08	0.84	-0.68
SAE-AISI 4130 Steel	253/265HB	Quenched & Tempered	895	778	1419	67		220	0.13	1359	1273	-0.08	1.51	-0.72
SAE-AISI 4340 Steel	237/247HB	Hot-rolled	826	634	1088	43		192	0.17	1384	1232	-0.1	0.53	-0.56
SAE-AISI 4340 Steel	350HB	Quenched & Tempered	1205	1140	1750	57		199	0.14	1862.96	1944.32	-0.1	1.22	-0.73
SAE-AISI 4340 Steel	400HB	Quenched & Tempered	1467	1371	1557	38		199	0.13	1950	1898	-0.09	0.67	-0.64
ALUMINUM 1100 ALLOYS														
1100 Al	28HB	As-received	110	97		87.6		69.05	0.159	184	159	-0.092	0.467	-0.613
ALUMINUM 2000/6000 ALLOYS														
2014-T6	135HB	As-received	511	463	628	25		69.05	0.072	704	776	-0.091	0.269	-0.742
2024-T3	120HB		486	360			17.3	72	0.04	590	1044	-0.114	1.765	-0.927
2024-T351	120HB		469	324	138			73.1	0.09	786.002	1013.53	-0.11	0.21	-0.52
2024-T4	120HB	STA	476	304	140	35		70.43	0.098	808	764	-0.075	0.334	-0.649
Alloy 6082	93HB	STA	330	290	95			70	0.051	397	611	-0.099	1.085	-0.857
ALUMINUM 5000 ALLOYS														
5456-H311	56HB	As-received	350	235	566	34.6		69.05	0.084	636	702	-0.102	0.2	-0.655
ALUMINUM 7000/8000 ALLOYS														
7075-T6	150HB		560	480	159			70	0.1	965.266	1316.9	-0.126	0.19	-0.52
7075-T61	150HB		565	470		33		70.5	0.081	883	1050	-0.099	0.355	-0.782
7075-T65	150HB		570	500				72	0.075	910	1294	-0.1	0.5	-0.915
7075-T73	140HB		500	410	160			70	0.032	510.212	799.792	-0.098	0.26	-0.73
7075-T7651	150HB		462	382			8.4	71	0.094	695	989	-0.14	6.812	-1.198
NICKEL BASED SUPER ALLOYS														

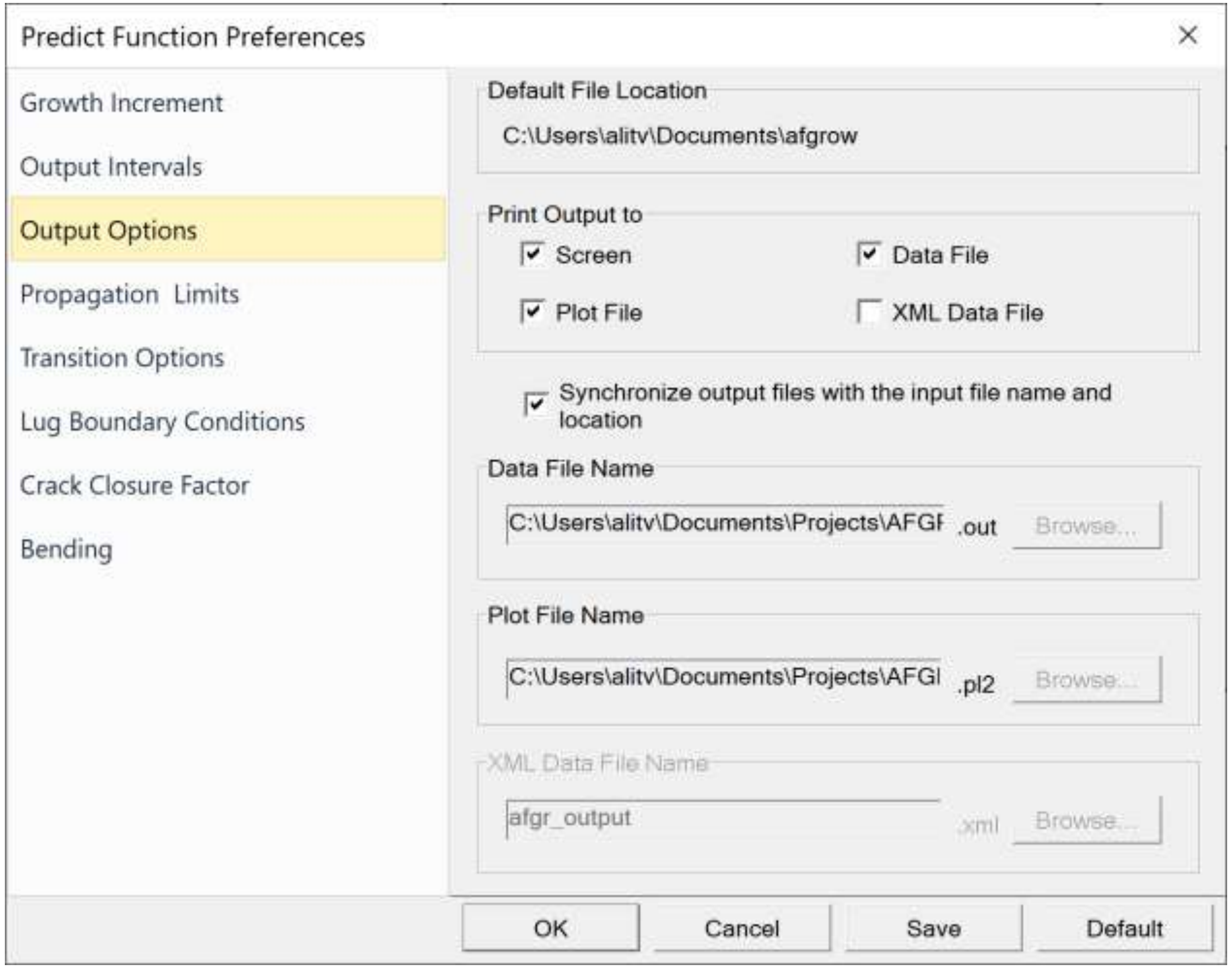
OK Cancel

Open Tabular Lookup Material Data File Using COM

```
Option Explicit
Private Sub CommandButton1_Click()
    Dim af As Afgrow.Application
    Set af = CreateObject("Afgrow.Application")

    af.Visible = True

    Dim mat As Afgrow.TabularLookupMaterial
    Set mat = af.SetTabularLookupMaterial

    Dim b As Boolean
    b = mat.OpenFile(Cells(2, 3))

    Dim young As Double
    young = mat.dYoungModulus
    mat.dUltimateStrength = 68

    af.ConstAmplitudeSpectrum 0#
    af.SMF = 14

    Dim Cycles As Double
    Dim finalC As Double
    Dim finalA As Double
    Dim finalCt As Double
    Dim finalKc As Double
    Dim finalKa As Double
    Dim finalKct As Double
    af.RunFrozPredict Cycles, finalC, finalKc, finalA, finalKa, finalCt, finalKct

    af.Quit
End Sub
```

Enhanced Output Preferences

- Add a check box to put output file in the same folder as input file.
- Allow the for each output file type to have the same name as an input file.



Option to Use Plug-in Models From COM

```
public static void RunPluginModelAdditions()
{
    Afgrow.Application af = new Afgrow.Application();
    af.Visible = true;
    af.PluginModel.LoadPlugin("VZLUPlugin.VZLUPluginClass");
    bool b = af.PluginModel.SetProperty("Crack Length", 0.25);\
    b = af.PluginModel.SetProperty("Bottom Length", 0.5);
    b = af.PluginModel.SetProperty("Top Length", 0.8);
    b = af.PluginModel.SetProperty("Top Radius", 0.9);
    b = af.PluginModel.SetProperty("Thickness", 0.3);

    double d = af.PluginModel.GetProperty("Crack Length");
    d = af.PluginModel.GetProperty("Bottom Length");
    d = af.PluginModel.GetProperty("Top Length");
    d = af.PluginModel.GetProperty("Top Radius");
    d = af.PluginModel.GetProperty("Thickness");

    af.ConstAmplitudeSpectrum(0.0);
    af.SMF = 14;

    double cycles;
    double Kc;
    double Ka;
    af.RunFrozPredict(out cycles, out _, out Kc, out _, out Ka, out _, out _);

    Console.WriteLine(cycles + "\n");
    Console.ReadLine();
    af.Quit();
}
```

Consist of 3 functions:

```
void LoadPlugin(BSTR fileName);

boolean SetProperty(BSTR propertyID, VARIANT value);

VARIANT GetProperty(BSTR propertyID);
```

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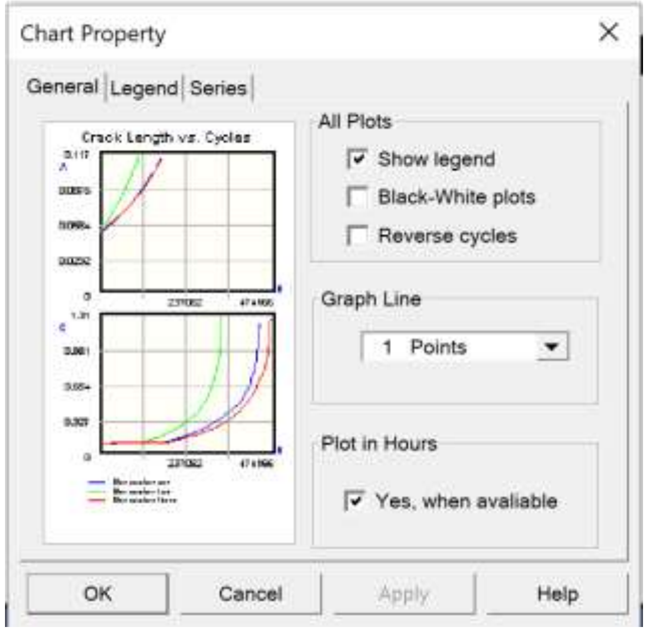
Life in Hours Output – What Do We Do with a Time Dependent Spectrum?

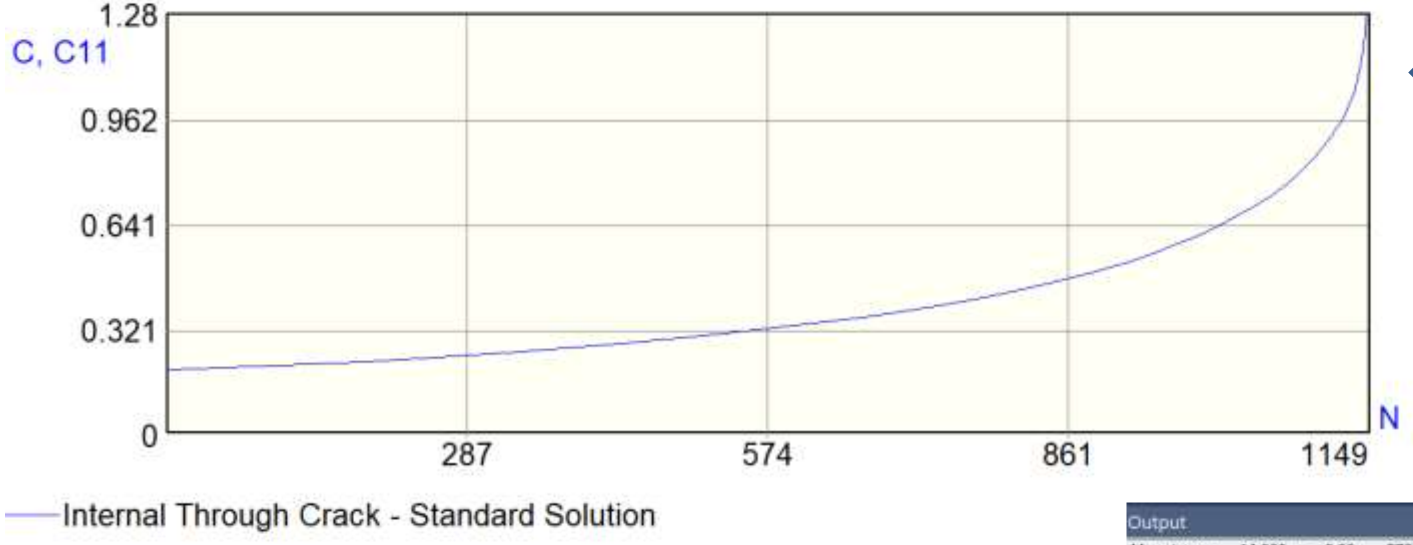
Print hours and cycles

```
C  Crack size=    1.089  Beta Tension= 1.2170 Beta Compression= 1.2170  R(k)= 0.0000  R(final)= 0.0000        Delta k=3.1513e+01  D()/DN=3.0626e-04
Max stress =   14.000  r = 0.00     57100  Cycles  Subspectra:       0  Pass:  572   Hours: 1142

C  Crack size=   1.1196  Beta Tension= 1.2498 Beta Compression= 1.2498  R(k)= 0.0000  R(final)= 0.0000       Delta k=3.2816e+01  D()/DN=4.4571e-04
Max stress =   14.000  r = 0.00     57200  Cycles  Subspectra:       0  Pass:  573   Hours: 1144

C  Crack size=   1.1642  Beta Tension= 1.2498 Beta Compression= 1.2498  R(k)= 0.0000  R(final)= 0.0000       Delta k=3.3463e+01  D()/DN=5.5443e-04
Max stress =   14.000  r = 0.00     57300  Cycles  Subspectra:       0  Pass:  574   Hours: 1146

C  Crack size=   1.2196  Beta Tension= 1.3171 Beta Compression= 1.3171  R(k)= 0.0000  R(final)= 0.0000       Delta k=3.6095e+01  D()/DN=2.1559e-03
Max stress =   14.000  r = 0.00     57400  Cycles  Subspectra:       0  Pass:  575   Hours: 1148
```



- Let user decide what to see in the plot view.
- “Crack Length vs. Cycles” graph will be in hours only if “Yes” button is checked in and plots are covetable to hours

New Life in Hours Output Options



The crack length plots converted to hours if the option to display life in hours is selected

Output intervals printed in "hours" if the option to display life in hours is selected

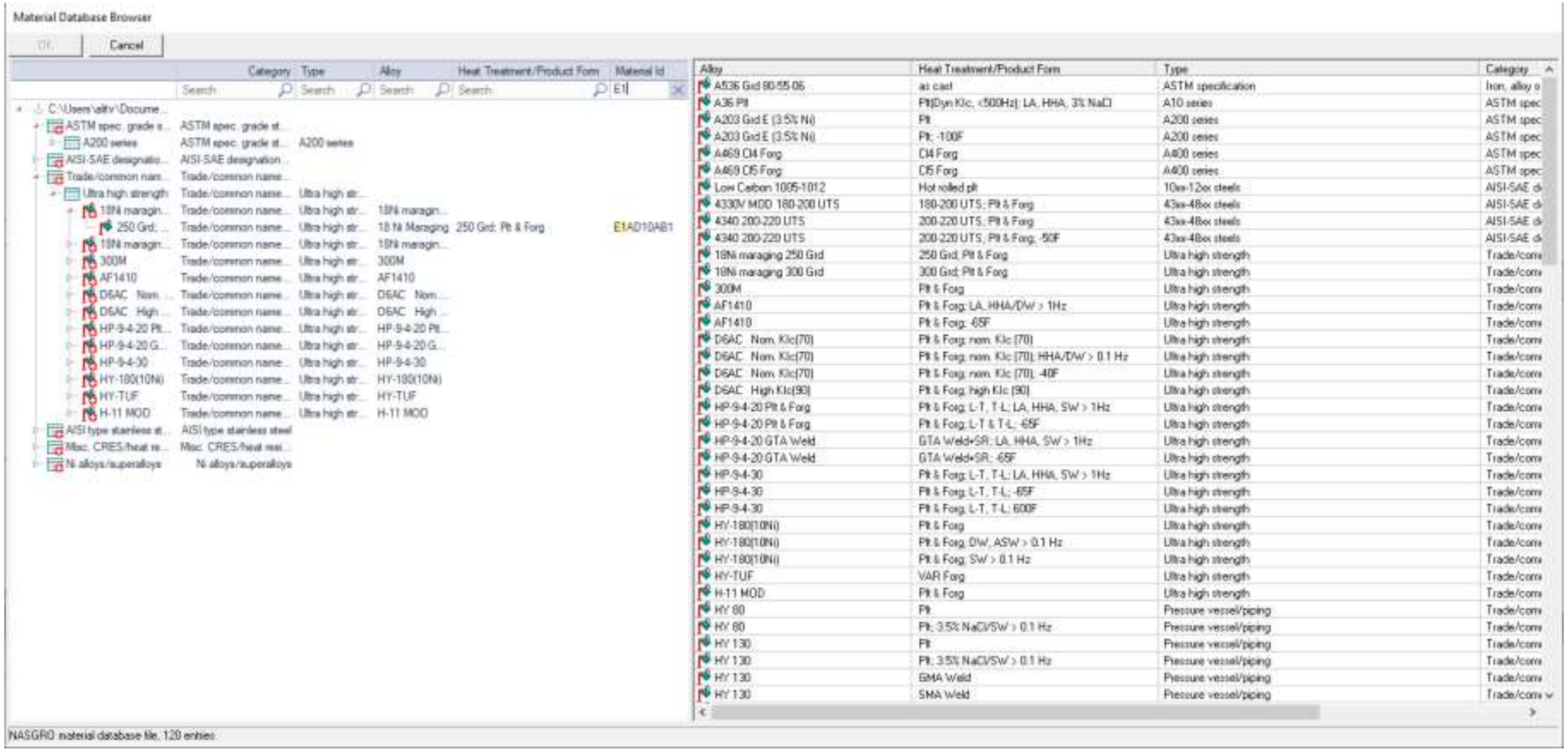
```
Output
Max stress =   14.000  r = 0.00     57000  Cycles  Subspectra:     0  Pass:  571   Hours: 1140

 C  Crack size=   1.089  Beta Tension= 1.2170 Beta Compression= 1.2170  R(k)= 0.0000  R(final)= 0.0000        Delta k=3.1513e+01  D()/DN=3.0626e-04
Max stress =   14.000  r = 0.00     57100  Cycles  Subspectra:     0  Pass:  572   Hours: 1142

 C  Crack size=   1.1196  Beta Tension= 1.2496 Beta Compression= 1.2496  R(k)= 0.0000  R(final)= 0.0000       Delta k=3.2816e+01  D()/DN=4.4571e-04
Max stress =   14.000  r = 0.00     57200  Cycles  Subspectra:     0  Pass:  573   Hours: 1144

 C  Crack size=   1.1642  Beta Tension= 1.2496 Beta Compression= 1.2496  R(k)= 0.0000  R(final)= 0.0000       Delta k=3.3463e+01  D()/DN=5.5443e-04
Max stress =   14.000  r = 0.00     57300  Cycles  Subspectra:     0  Pass:  574   Hours: 1146

 C  Crack size=   1.2196  Beta Tension= 1.3171 Beta Compression= 1.3171  R(k)= 0.0000  R(final)= 0.0000       Delta k=3.6095e+01  D()/DN=2.1559e-03
Max stress =   14.000  r = 0.00     57400  Cycles  Subspectra:     0  Pass:  575   Hours: 1148

*********Fracture based on ' Kmax' Criteria (current maximum stress)
 C  Crack size=   1.2821  Beta Tension= 1.3677 Beta Compression= 1.3677  R(k)= 0.0000  R(final)= 0.0000       Delta k=3.8429e+01  D()/DN=1.0000e-02
Max stress =   14.000  r = 0.00     57429  Cycles  Subspectra:     0  Pass:  575   Hours: 1148.58

Stress State in the 'C' direction (PSC): 2
Fracture has occurred- run time:  0 hour(s)  0 minute(s)  1 second(s)
1148.5800 hours have passed
```

LexTech

AFGROW .NET

NASGRO Material Model Changes

- Improved data selection
- Material code is displayed in the output
- Material code is saved in the AFGROW problem definition file



Prediction Result Information in AFGROW Output XML file

```xml
    </Event>
    <Result code="0" cycles="57429" spectrum_units="1" spectrum_unit_name="Constant amp." spectrum_pass="575">
        <Crack id="0">
            <Dim id="C" length="1.28211" beta_tension="1.36772" beta_compression="1.36772" delta_k="38.4293" dl_dn="0.01" r_k="0" r_final="0"/>
        </Crack>
    </Result>
</CrackGrowthOutput>
```

Prediction result code

Number of cycles before prediction stopped

Final length and additional information for every crack direction

Additional spectrum related information

API 579 *Stress Intensity Factor Solutions*

ID	Name	Load	Stress Distribution	Classic Model Equivalent
5010	Longitudinal Through Crack In Cylinder (9B.5.1)	Pressure		2098
5030	Circumferential Through Crack In Cylinder (9B.5.3)	Pressure		2090
5040	Infinite Longitudinal Surface Crack In Cylinder (Internal) (9B.5.4)	Stress	Polynomial	
5041	Infinite Longitudinal Surface Crack In Cylinder (External) (9B.5.4)	Stress	Polynomial	
5060	Infinite Longitudinal Surface Crack In Cylinder (Internal) (9B.5.6)	Stress	WF	
5061	Infinite Longitudinal Surface Crack In Cylinder (External) (9B.5.6)	Stress	WF	
5070	Circumferential Crack In Cylinder (Internal) (9B.5.7)	Pressure		2096
5071	Circumferential Crack In Cylinder (External) (9B.5.7)	Pressure		2095
5090	Circumferential Crack In Cylinder (Internal) (9B.5.9)	Stress	WF	
5091	Circumferential Crack In Cylinder (External) (9B.5.9)	Stress	WF	
5100	Longitudinal Surface Crack In Cylinder (Internal) (9B.5.10)	Pressure		1091
5101	Longitudinal Surface Crack In Cylinder (External) (9B.5.10)	Pressure		1092
5110	Longitudinal Surface Crack In Cylinder (Internal) (9B.5.11)	Stress	Polynomial	
5111	Longitudinal Surface Crack In Cylinder (External) (9B.5.11)	Stress	Polynomial	
5120	Longitudinal Surface Crack In Cylinder (Internal) (9B.5.12)	Stress	WF	3030
5121	Longitudinal Surface Crack In Cylinder (External) (9B.5.12)	Stress	WF	3040
5130	Circumferential Surface Crack In Cylinder (Internal) (9B.5.13)	Pressure		
5131	Circumferential Surface Crack In Cylinder (External) (9B.5.13)	Pressure		1090
5140	Circumferential Surface Crack In Cylinder (Internal) (9B.5.14)	Stress	Polynomial	
5141	Circumferential Surface Crack In Cylinder (External) (9B.5.14)	Stress	Polynomial	
5180	Longitudinal Full-Elliptic Embedded Crack in Cylinder (9B.5.18)	Stress	Polynomial	
5190	Full-Elliptic Embedded Crack in Cylinder (9B.5.19)		Polynomial	

Acknowledgements

- A-10 and T-38 Structural Integrity and Analysis Group
- ASIMIS
- AFGROW Customers and Consortium Members

Questions