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RamSeries - Validation Case 41

Fatigue Damage Assessment

RamSeries

Version
15.1.0

http://www.compassis.com
info@compassis.com
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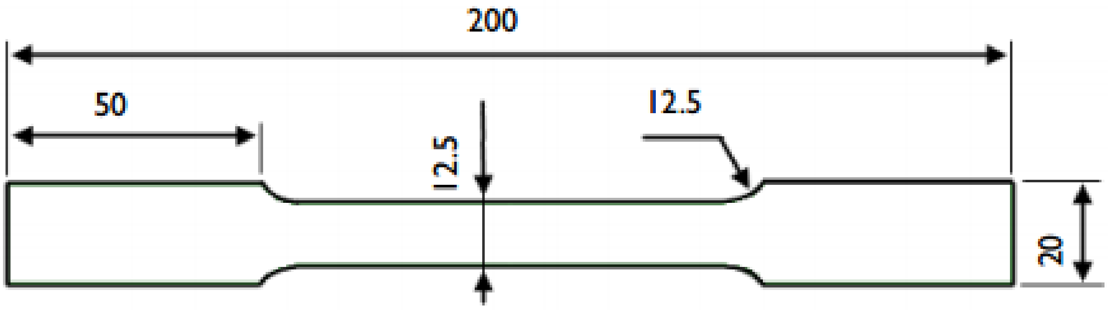
Model Description

In this benchmark model for the Rainflow counting algorithm, values computed by the Fatigue danmage Assessent tool in RamSeries are compared with the ASTM standard E1049-85 (Ref. 1).

An extension to the benchmark compares the Palmgren-Miner cumulative damage model to analytical expressions.

The dimensions of the specimen are shown in the next image:



Flat test specimen. Dimensions in mm

The specimen thickness is t=6.25 mm.

The test specimen is subjected to a repeated load cycle. An ASTM cycle (Ref. [1]) is evaluated in the example. The load history of the cycle is presented in the following table:

Step	Load Units
1	-2
2	1
4	5
5	-1
6	3
7	-4
8	4
9	-2

The unit load corresponds to 10 MPa stress in the central cross section.

The material is assumed to be linear elastic:

$E = 69.0e10^9$ Pa

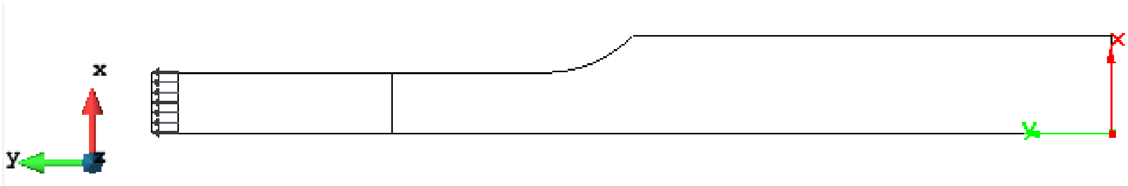
$\mu = 0.34$

Results

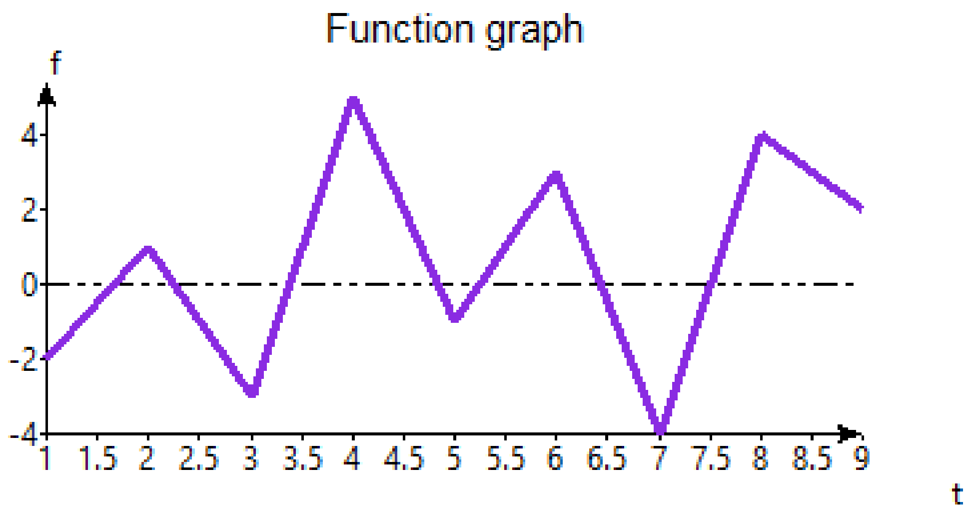
For the sake of validation, a simulation was run using the properties described in the previous section. The load and conditions are applied as follows:

Loads:

A boundary pressure in the Y direction is applied in the middle section, with the following unit load and evolution:



Y_{press}= 10.0e6*12.5e-3*0.5 = 62500 N/m



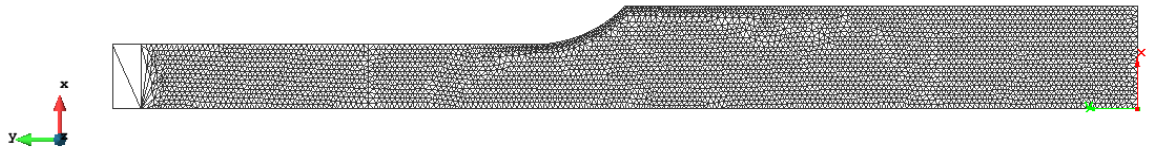
The simulation has been performed using an implicit Bossak-Newmark algorithym, with 10 time steps, dt = 1.0 s.

Conditions:

Only a quarter of the specimen is modelled, so the corresponding symmetry conditions are applied, together with the full restriction in the clamped edge.

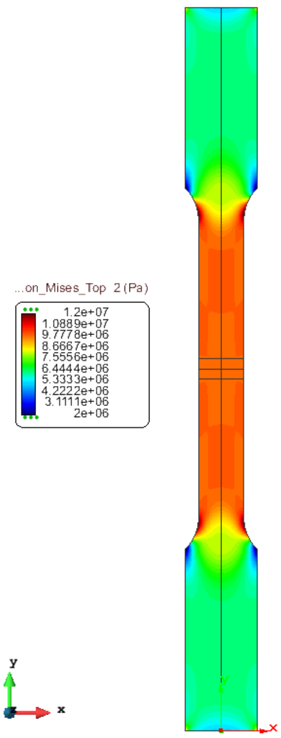
Mesh:

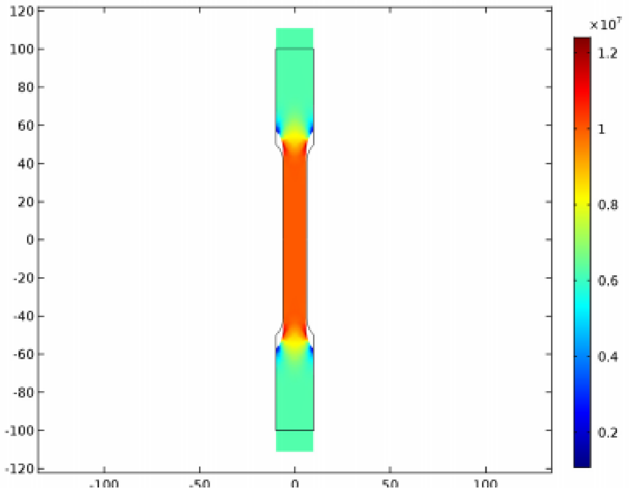
A mesh of 7448 linear triangles (DKT) has been used (3955 nodes).


x
y

Stress results:

The result obtained in RamSeries (left) for the axial stress in the specimen caused by a unit load, is shown in the next image, compared to the result of Ref. [2] (right):





Rainflow counting results:

The Fatigue Damage Assessment tool generates results for the cycle counting algorithm as well as for damage calculation. The applied load cycle is quantified with the Rainflow Counting algorithm. The following tables show the results for each level cycles, stress amplitudes, mean stress, stress ranges, and stress evaluated at the bin center, for RamSeries and COMSOL:

Level	Cycles (n)	S_amplitude [Mpa]	S_mean [Mpa]	S_amplitude_b [Mpa]	R	Nc
0	0.5	45	5	44.55	-0.798	1.17E+06
11	1	40	-4	39.65	-1.224	1.94E+08
33	0.5	30	10	29.85	-0.498	3.54E+05
55	1.5	20	3.75	20.05	-0.685	2.18E+08
66	0.5	15	-13.33	15.15	-15.648	3.11E+22
77	0.5	10	-10	10.25	-81.000	6.59E+30

Results for RamSeries

σ_a (MPA)	σ_m (MPA)	$\sigma_a{}^b$ (MPA)	$\sigma_m{}^b$ (MPA)	R^b	n^b	N^b
20.0	-10.0	21.4	-8.0	-2.19	0.500	Inf
15.0	-5.0	17.1	-4.0	-1.61	0.500	Inf
40.0	0.0	38.6	0.0	-1.00	0.500	3.44e7
45.0	5.0	42.9	4.0	-0.829	0.500	2.31e6
40.0	10.0	38.6	8.0	-0.656	0.500	5.84e5
30.0	10.0	30.0	8.0	-0.579	0.500	1.45e6
20.0	10.0	21.4	8.0	-0.456	1.00	2.47e6

Results for COMSOL

Fatigue damage results:

The evaluation of the cumulative damage is compared against analytical expressions, using Palmgren-Miner model. The number of cycles to failure for a constant cycle is taken from the S-N curve which is evaluated at the center of each interval.

The S-N curve used in this case is the Wöhler diagram, given by the following expression:

$$\sigma_a\ [\text{MPa}] = 94.0*(R/-0.36)^{1.15}*N^{-0.119}$$

Where:

- σ_a^b: Stress amplitude at the center of the bin
- R= $\sigma_{min}/\sigma_{max}$: R-value (valid for -2.5 ≤ R ≤ -0.2)
- N : Number of cycles to failure (values of N ≥ 1.0e8 are seen as an infinite value and are not taken into account in the damage calculations).

The stress amplitude is evaluated for the center of each interval (constant cycle level), by means of the upper and lower stress ranges, and the cycle stress amplitude given for such level:

$$\sigma_a^b = (\sigma_{range}^{up} + \sigma_{range}^{down})*0.5 - \sigma_a^{cycle}$$

The maximum and minimum stresses needed for evaluating R-value, are calculated from the mean stress for each interval:

$$\sigma_{min} = \sigma_{mean} - \sigma_a^b$$

$$\sigma_{max} = \sigma_{mean} + \sigma_a^b$$

The fatigue damage factor following the Palmgren-Milner linear damage rule is calculated using the expression:

$$f_{dam} = m * \Sigma_{i=1}^{p} (n_i^b / N_i^b)$$

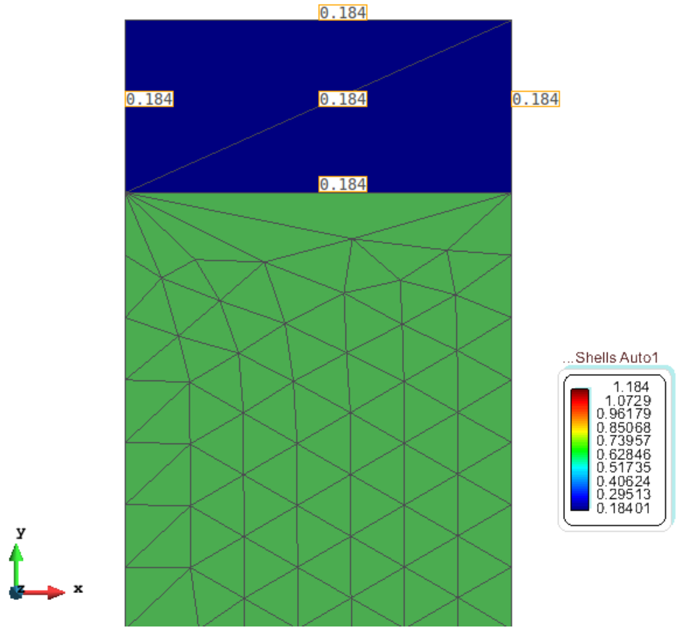
Where:

m=1.0e5 (number of repeatable blocks)

p: number of bins (intervals)

The obtained results are the following:

	f_{dam}
RamSeries	0.184
ASTM	0.184
COMSOL	0.182



The small discrepancies between results is attributed to the evaluation of the S-N curve.

The Fatigue Damage Assessment model is based on the Palmgren-Miner linear damage rule. It is a discrete model in the sense that the calculations are based on stress bins (intervals) which holds all stress cycles within a certain stress amplitude and mean stress range.

For this example (in COMSOL), the stress amplitude range in an interval (N_m) and the mean stress range in an interval (N_r), are:

N_m=20 MPa/5= 4 MPa

N_r=30 MPa/7= 4.3 MPa

In RamSeries the discretization used is 100 intervals. Changes in the bin discretization, will change the counted stress cycles. The damage is evaluated based on the bin stress and not true cycle stresses. Consider the cycle defined by σ_a = 45.0 MPa; it is evaluated in a bin defined by σ_a^b = 42.95 MPa. Since bin stresses are lower than true stresses in that cycle, they predict less damage and thus give a nonconservative contributions to the fatigue damage factor.

References

[1] ASTM International, Standard Practices for Cycle Counting in Fatigue Analysis, Designation: E1049-85 (reapproved 2011).

[2] Cycle Counting in Fatigue Analysis - Benchmark (COMSOL)

Validation Summary

CompassFEM version	15.1.0
Tdyn solver version	15.1.0
RamSeries solver version	15.1.0
Benchmark status	Successfull
Last validation date	27/11/2018