Fatigue tests of the UD reference material (GEV206-D02-00) using Risø geometry for the test coupons

25th November 2003

(CA fatigue at reference conditions, R=0.1)

Confidential

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TG3[2]

Modris Megnis

Povl Brøndsted

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[2]

Issue/revision	date	pages	Summary of change
0	Nov. 20, 2003	Na	Na
1	Nov. 25, 2003	4,5	new data added
2	Nov. 25, 2003	5	VUB, T-T data are added

1 Introduction

The constant amplitude (CA) fatigue test of GEV206 system in fiber direction is carried out and results are reported in this document. The test has been carried out at ambient room conditions (OPTIMAT reference conditions). The results obtained by using RISOE dog bone shape specimens are presented at this point. The additional test, where the OPTIMAT standard specimens are used will be added, and results will be compared in the future.

This work is a part of the work package 8, OPTIMAT TG3, and is carried out according to DPA of TG3.

The experimental procedures, manufacturing of the specimens and experimental set up is described in "Experimental" part of the report.

2 Specimens and materials

The specimen geometry for the RISOE dog bone specimen is illustrated in Figure 1. The extensometer with the gauge length of $25\,[mm]$ was used to measure the strain through out the fatigue test. The strain-stress hysteresis loops were used later to calculate the stiffness degradation as a function of number of cycles.

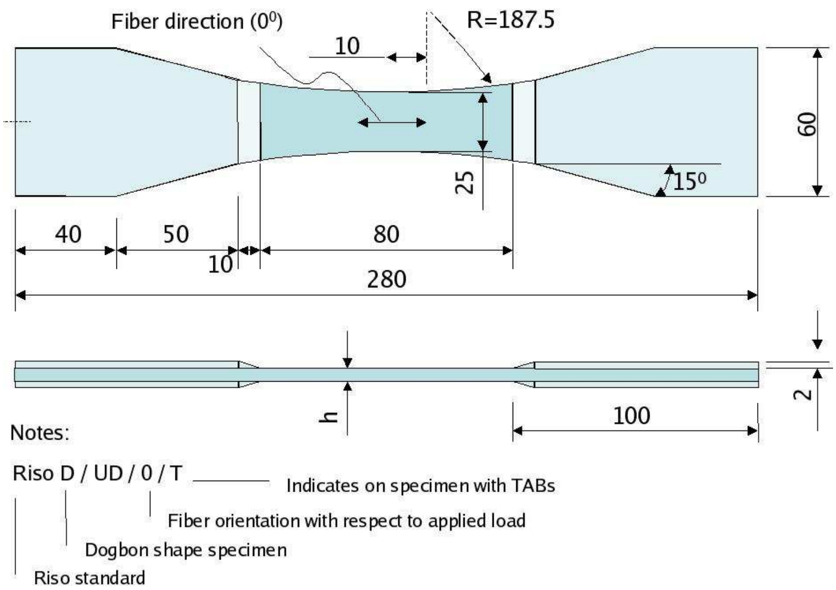


Figure 1: Geometry of the RISOE dog bone specimen.

The list of tested specimens and corresponding testing conditions are given in Table 2 together with the results of the fatigue test.

3 Test procedures and measurements

Load controlled test

Constant dissipated energy test conditions (constant hysteresis loop). The whole cycle is periodically recorded, recording it more frequently at the end of the life time. In total, approximately 7 recorded loops per test.

Strain and displacement are measured through out the test

The predefined stress or strain levels are irrelevant, but are helpful as they can serve as a guideline for planning and carry out the test. The irrelevance is because different approach is used in order to calculate S-N statistics.

4 Results and discussion

4.1 Static tests

Table 1: Results of static tensile test, GEV206-D02-00, RT.

Specimen ID	w (mm)	h (mm)	ε_{max} $(\%)$	E_x (MPa)	σ_{max} (MPa)	P_{max} (kN)
GEV206-I01-00-01	24.82	3.84	3.60	40.10	787.68	74.97
GEV206-I01-00-02	24.82	3.82	2.31	34.11	768.48	72.86
GEV206-I01-00-03	24.71	3.86	2.23	44.27	811.41	77.43
GEV206-I01-00-04	24.81	3.79	2.52	36.80	823.70	77.49
GEV206-I01-00-06	24.81	3.89	2.48	44.10	779.13	75.15
GEV206-I01-00-07	24.81	3.88	2.41	37.98	806.51	77.61
GEV206-I01-00-08	24.82	3.91	2.40	39.62	825.14	80.15
GEV206-I01-00-09	24.85	3.90	2.31	38.13	799.82	77.59
GEV206-I01-00-10	24.78	3.87	2.00	36.01	822.93	78.95

4.2 T-T fatigue, R=0.1

The number of specimens tested, the corresponding loading and results of fatigue lifetime are given in 2.

The fatigue lifetime diagram is presented as $\epsilon - N$ curve, and it is described by power law function, $N = K\varepsilon^{-m}$, also called model. The constants m and K are calculated by fitting the model in log-log scale. Also the 95/95 confidence limit (tolerance bound) is calculated. The approach proposed by Ronold and Echtermeyer is used for calculating the tolerance bound. Both, the experimental data, and model fit with its tolerance bound is given in Figure ??.

Table 2: Results of fatigue test, GEV206-D02-00, R=0.1, RT

Specimen ID	w (mm)	h (mm)	ε_{max} $(\%)$	E_x (GPa)	σ_{max} (MPa)	P_{max} (kN)	P_{min} (kN)	f (Hz)	N_f
GEV206-D02-00-04	24.89	3.67	0.50	39.00	195	17.81	1.78	10.0	
GEV206-D02-00-05	24.85	3.72	0.55	40.00	215	19.83	1.98	8.3	1965500
GEV206-D02-00-06	24.86	3.73	0.60	39.60	238	22.03	2.20	5.1	517120
GEV206-D02-00-07	24.86	3.84	0.65	39.00	254	24.20	2.42	5.9	
GEV206-D02-00-08	24.83	3.70	0.70	39.75	278	25.56	2.56	5.1	153660
GEV206-D02-00-09	24.93	3.75	0.75	39.00	293	27.35	2.73	4.4	
GEV206-D02-00-10	24.65	3.72	0.80	40.13	321	29.44	2.94	3.9	98160
GEV206-D02-00-12	24.77	3.70	0.90	41.20	371	33.98	3.40	3.1	46580
GEV206-D02-00-13	24.84	3.78	0.95	40.00	380	35.68	3.57	2.8	19080
GEV206-D02-00-14	24.76	3.60	1.00	40.22	402	35.85	3.59	2.5	19260
GEV206-D02-00-15	24.66	3.59	1.05	41.27	433	38.36	3.84	2.3	13460
GEV206-D02-00-11	24.91	3.71	1.15	39.00	332	30.64	3.06	2.0	3800

Table 3: Results of the fatigue test, GEV206-R03-00, R=0.1, RT, VUB

Specimen ID	w (mm)	h (mm)	ε_{max} $(\%)$	E_x (GPa)	σ_{max} (MPa)	P_{max} (kN)	P_{min} (kN)	f (Hz)	N_f	Notes
GEV 206 R0300-0307	25.39	3.74	1.62	36.84	579.1	55.00	5.50	1.5	1213	
GEV 206 R0300-0308	25.45	3.75	1.00	36.84	366.7	35.00	3.50	3.57	55253	
GEV 206 R0300-0299	25.51	3.75	0.77	35.60	261.1	25.00	2.50	5	330217	
GEV 206 R0300-0298	25.48	3.72	0.63	36.36	211.0	20.00	2.00	5	185426	

The procedure of the fitting the model to experimental data points is straight forward done by linear regression in “log-log” scale. The methodology is also detailed described and discussed in [1] nevertheless, for better consistency of this report, it is shortly outlined in section 6. The procedures that are used in order to calculate the tolerance bound are also given by [1] and shortly outlined in 6.

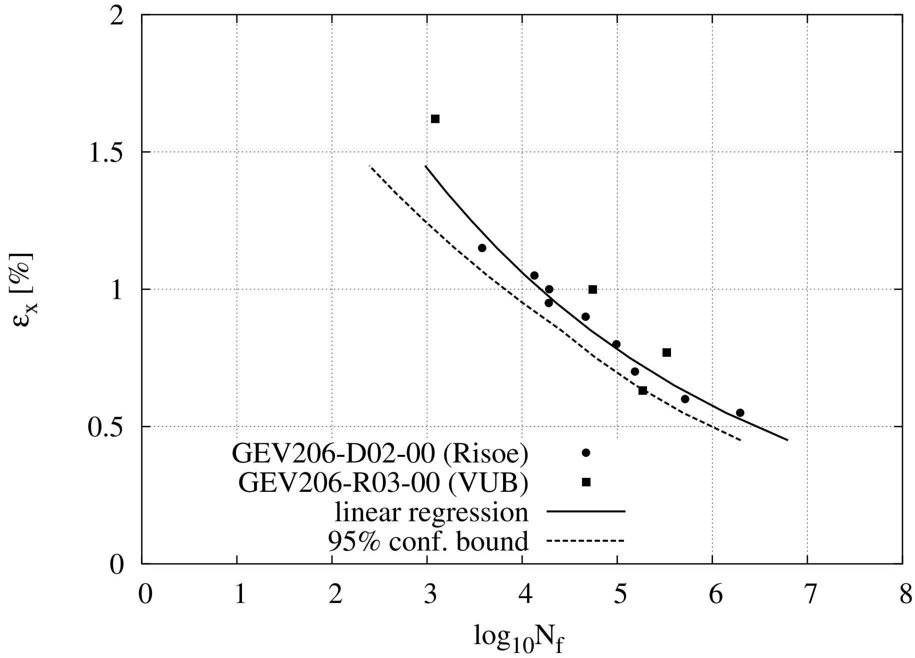
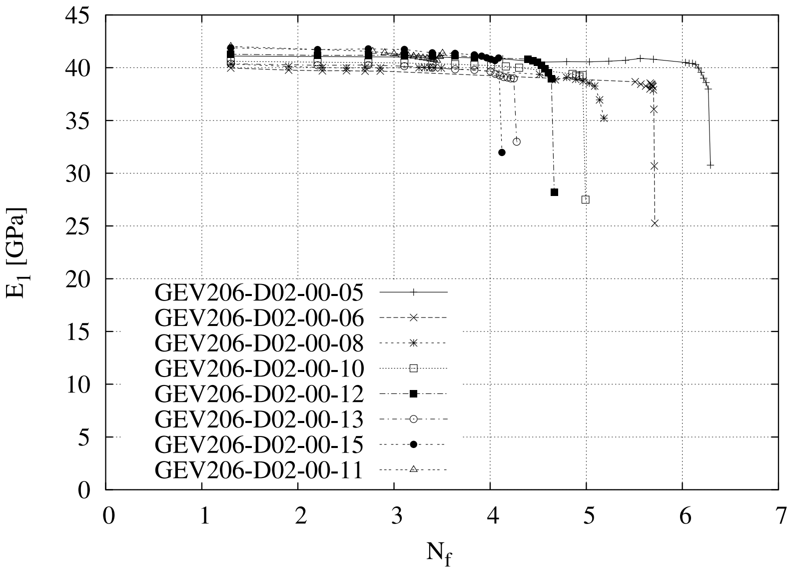


Figure 2: T-T fatigue, R=0.1. Material, GEV206-00. The constants for model are calculated as $N = 1.7466e + 04\varepsilon^{-7.1916}$. The model is fit to the Risoe data only.

Two more points will be added to the life diagram in the future.

The stiffness degradation is measured during the fatigue test. The results of the stiffness degradation are given in Figure 3, and numerical values are available in Table 4.



Specimen ID	ε_{max} (%)
GEV206-D02-00-05	0.55
GEV206-D02-00-06	0.60
GEV206-D02-00-08	0.70
GEV206-D02-00-10	0.80
GEV206-D02-00-12	0.90
GEV206-D02-00-13	0.95
GEV206-D02-00-15	1.05
GEV206-D02-00-11	1.15

Figure 3: Measurements of stiffness degradation as function of number of cycles.

Table 4: T-T fatigue, R=0.1. Material, GEV206-00. Measurements of stiffness degradation.

GEV206-D02-00-05		
N_f	$E_x[GPa]$	$\frac{E_i}{E_0}$
20	41.11	1.0000
4000	40.99	0.9971
13500	40.85	0.9937
32000	40.53	0.9859
62500	40.57	0.9869
108000	40.56	0.9866
171500	40.62	0.9881
256000	40.7	0.9900
364500	40.88	0.9944
500000	40.8	0.9925
1078000	40.5	0.9852
1176000	40.42	0.9832
1274000	40.42	0.9832
1372000	40.31	0.9805
1470000	39.97	0.9723
1568000	39.57	0.9625
1666000	39.01	0.9489
1764000	38.59	0.9387
1862000	37.98	0.9239
1960000	30.76	0.7482

GEV206-D02-00-06		
N_f	$E_x[GPa]$	$\frac{E_i}{E_0}$
20	39.97	1.0000
80	39.77	0.9950
180	39.71	0.9935
320	39.72	0.9937
500	39.68	0.9927
720	39.69	0.9930
323100	38.67	0.9675
369300	38.44	0.9617
415400	38.26	0.9572
461600	37.99	0.9505
462100	38.54	0.9642
472600	38.42	0.9612
478100	38.43	0.9615
483600	38.34	0.9592
489100	38.25	0.9570
494600	38.20	0.9557
500100	37.90	0.9482
505600	36.06	0.9022
511100	30.69	0.7678
516600	25.26	0.6320

GEV206-D02-00-08		
N_f	$E_x[GPa]$	$\frac{E_i}{E_0}$
20	40.35	1.0000
80	40.12	0.9943
180	40.02	0.9918
320	39.97	0.9906
500	40.01	0.9916
720	39.98	0.9908
1820	40.00	0.9913
2080	40.02	0.9918
2340	40.00	0.9913
2600	39.99	0.9911
3100	39.97	0.9906
32600	39.37	0.9757
47600	38.86	0.9631
62600	39.09	0.9688
77600	38.90	0.9641
92600	38.74	0.9601
107600	38.53	0.9549
122600	38.27	0.9485
137600	36.95	0.8712

Table 5: T-T fatigue, R=0.1. Material, GEV206-00. Measurements of stiffness degradation.

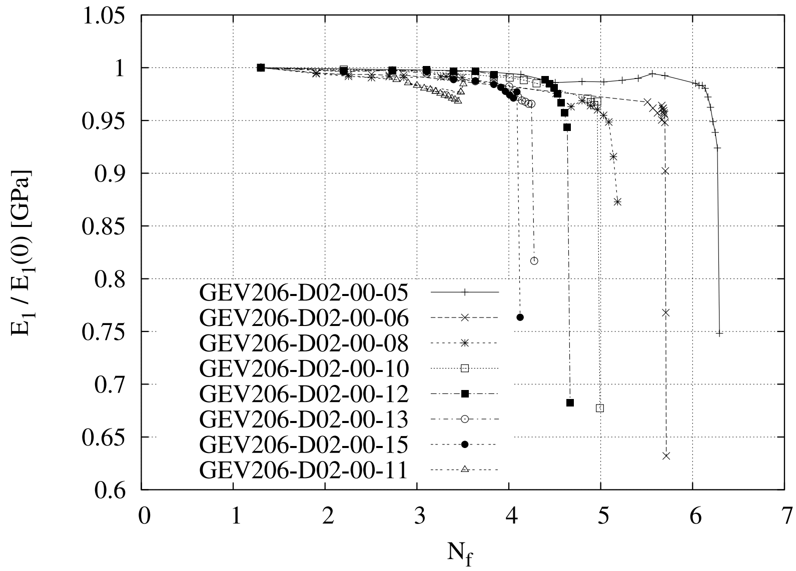
GEV206-D02-00-10			GEV206-D02-00-12			GEV206-D02-00-13		
N_f	$E_x[GPa]$	$\frac{E_i}{E_0}$	N_f	$E_x[GPa]$	$\frac{E_i}{E_0}$	N_f	$E_x[GPa]$	$\frac{E_i}{E_0}$
20	40.60	1.0000	20	41.28	1.0000	20	40.37	1.0000
160	40.53	0.9983	160	41.17	0.9973	160	40.23	0.9965
540	40.49	0.9973	540	41.18	0.9976	540	40.26	0.9973
1280	40.45	0.9963	1280	41.19	0.9978	1280	40.15	0.9946
2500	40.37	0.9943	2500	41.14	0.9966	2500	40	0.9908
4320	40.33	0.9933	4320	41.14	0.9966	4320	39.85	0.9871
6860	40.26	0.9916	6860	41.01	0.9935	6860	39.8	0.9859
10240	40.22	0.9906	24800	40.81	0.9886	10080	39.65	0.9822
14580	40.12	0.9882	27900	40.66	0.9850	11340	39.41	0.9762
20000	40.00	0.9852	31000	40.5	0.9811	12600	39.26	0.9725
71940	39.41	0.9707	34100	40.26	0.9753	13860	39.12	0.9690
78480	39.27	0.9672	37200	39.91	0.9668	15120	39.07	0.9678
85020	39.16	0.9645	40300	39.52	0.9574	16380	38.99	0.9658
91560	39.30	0.9680	43400	38.95	0.9436	17640	38.99	0.9658
98100	27.50	0.6773	46500	28.18	0.6827	18900	32.98	0.8169

Table 6: T-T fatigue, R=0.1. Material, GEV206-00. Measurements of stiffness degradation.

GEV206-D02-00-15		
N_f	$E_x[GPa]$	$\frac{E_i}{E_0}$
20	41.88	1.0000
160	41.72	0.9962
540	41.79	0.9979
1280	41.73	0.9964
2500	41.41	0.9888
4320	41.36	0.9876
6860	41.22	0.9842
8160	41.1	0.9814
9180	40.94	0.9776
10200	40.8	0.9742
11220	40.68	0.9713
12240	40.92	0.9771
13260	31.97	0.7634

GEV206-D02-00-11		
N_f	$E_x[GPa]$	$\frac{E_i}{E_0}$
20	42.02	1.0000
600	41.54	0.9886
1600	41.07	0.9774
3000	41.05	0.9769
800	41.41	0.9855
1000	41.31	0.9831
1200	41.20	0.9805
1400	41.15	0.9793
1600	41.07	0.9774
1800	40.99	0.9755
2000	40.92	0.9738
2200	40.88	0.9729
2400	40.80	0.9710
2600	40.75	0.9698
2800	40.68	0.9681
3000	41.05	0.9769
3200	41.37	0.9845

The same in normalized form is given in Figure 4. There is obvious connection between the applied strain level, life time and stiffness degradation reviled in both, Figure 3 and Figure 4. The more detailed analysis of the stiffness degradation, and stiffness based life time predictions are left out of the scope of this report. This topic will be undressed in separate report.



Specimen ID	ε_{max} (%)
GEV206-D02-00-05	0.55
GEV206-D02-00-06	0.60
GEV206-D02-00-08	0.70
GEV206-D02-00-10	0.80
GEV206-D02-00-12	0.90
GEV206-D02-00-13	0.95
GEV206-D02-00-15	1.05
GEV206-D02-00-11	1.15

Figure 4: T-T fatigue, R=0.1. Material, GEV206-00. The measurements of stiffness degradation in normalized form.

5 Concluding remarks

The CA fatigue tests are carried out for UD of GEV206 at ambient room conditions. The fatigue life diagram is presented as $\epsilon - N$ curve represented with 8 points. Two more points will be added in the future.

The stiffness degradation is measured as function of number of cycles for corresponding applied strain level.

6 Data reduction

In general the fatigue data can be presented in strain formulation, $\varepsilon - N$ as schematically shown in Figure 5

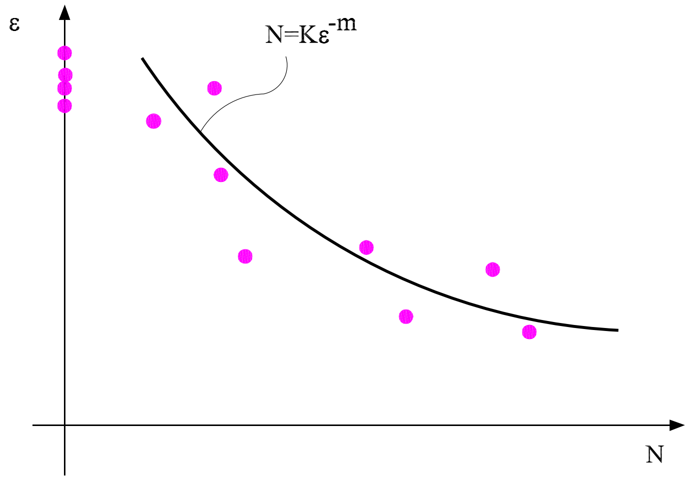


Figure 5: $\epsilon - N$ model.

The relationship between applied strain and number of cycles to failure are assumed to follow a power low function (it is also called, "model")

$$N = K\varepsilon^{-m} \tag{1}$$

where K and m are supposed to characterize material properties. These constants are calculated by using least squares method, fitting (1) as a straight line to experimental data of $\varepsilon - N$ in double "log-log" domain

$$\lg_{10} N = \lg_{10} K - m \lg_{10} \varepsilon. \tag{2}$$

It is easy to see that (2) describes straight line of form

$$y = b - mx, \tag{3}$$

where, $y = \lg_{10} N$, $b = \lg_{10} K$, and $x = \lg_{10} \varepsilon$.
The linear fit of (2) or (3) is shown schematically in Figure 6

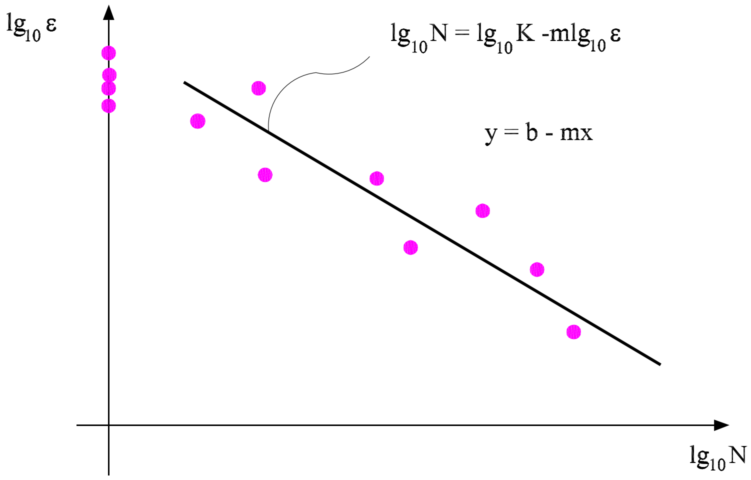


Figure 6: Linear fit in lg-lg domain.

The constants b and m are calculated directly by fitting the (2) or (3) to the data by least squares method, from where constant, K, for the model is calculated as, $K = 10^b$. Further these constants are used back into (1).

The statistical tolerance bound (illustrated in Figure 7) is constructed as for random normal variable

$$Y_i = y\left(x_i\right) \pm c^i_{1-\alpha,\gamma} s, \tag{4}$$

where $y\left(x_i\right) = \lg_{10} N_i$ is given by (??), and the coefficient $c^i_{1-\alpha,\gamma}$ is calculated for any Δx_i as

$$c^i_{1-\alpha,\gamma} = 1.645 + 2.567\left(n-2\right)^{-0.71} + \frac{5.588}{\sqrt{n-2}}\frac{\Delta x_i}{L_x}. \tag{5}$$

The deviation of current value x_i from mean $\overline{x}$ of all data, Δx_i is defined as

$$\Delta x_i = \left|x_i - \overline{x}\right|, \tag{6}$$

and length of the interval within which the all considered data are uniformly distributed is given by

$$L_x = \left|x_{\max} - x_{\min}\right|. \tag{7}$$

The standard deviation used in (4) is calculated according to

$$s = \sqrt{\frac{\sum\limits_i^n \left(y_i - y\left(x_i\right)\right)^2}{\left(n-1\right)}}. \tag{8}$$

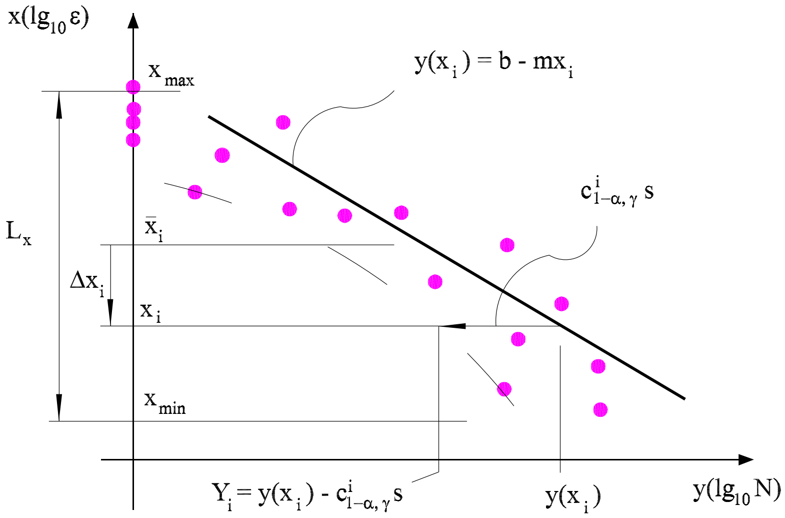


Figure 7:

References

[1] Ronold, K.O. and Echtermeyer, A.T. (1996), "Estimation of fatigue curves for design of composite laminates", Composites Part A, 27A, pp.489-491