BAM - III.2: WG
Pressure Equipment - Pressure Receptacles;
Fuel Gas Storage Systems

Dr. Georg W. Mair
☎ +49 30 8104-1324
e-mail: georg.mair@BAM.de

Berlin, the 11th January 2010

Load Cycle Test Requirements - Material Specific Scatter

As already explained by document SGS-4-8 - (Germany) BAM – “Generals on Storage Systems and Comments on J2579” during the 4th meeting of the Informal Group on Hydrogen and Fuel Cell Vehicles - sub group safety (HFCV-SGS) at JASIC in Tokyo (Japan) from 24-26 September 2008 the current treatment of load cycle test results of performance based tests may lead to misinterpretation of safety aspects.

As demonstrated by the following slides 1 -5 (created for an ISO-meeting on retesting standards in 2009) the scatter of carbon or other fibres is significantly higher than of metal liners. This means that the currently agreed tests (by which it is to demonstrate that after a harmonised and general number of load cycles no leakage occurs) have an enormously higher uncertainty with respect to Carbon fibres than with respect to metal parts. Luckily the experience with type III cylinders of the last decades shows under normal conditions that with respect to the stress ratios metal liners failed before the composite wrapping became critical.

Hence we have the choice between three opportunities concerning type IV cylinders:

1. We keep the load cycle requirements as they are. But: By this we cement the purpose of load cycle tests of type IV cylinders to safety assessment of metal parts (boss) only. This means simultaneously that the general estimation of static fatigue by stress ratio stays to be the only resilient safety requirement with respect to fatigue of the solely load carrying composite.

or

2. We require the number of minimum load cycles dependent from the fibre type and increase this number (significantly) for type IV cylinders, so that an equivalent reliability level is demonstrated as it is demonstrated by performing much less load cycles at type III cylinders. But this would increase the effort for cycle tests of CFRP-type IV-cylinders enormously (CFRP compared with Aluminium: about 25 times).

or

3. We introduce a new test (stress rupture tests = creep to burst test = sustained load test), which allows to assess the significance of the stress ratios for each design individually (compare slides 6 – 8).

This is valid for all kinds of cycle tests whether for the initial hydraulic cycle test or for the check of residual life after e.g. gaseous cycling.

Slide 1: Graphic definition/explanation of the parameter “Streuspanne” T_N by lines of constant survival rate. This parameter is used for describing the scatter in a diagram for fatigue degradation (Wöhler-diagram).

Slide 2: Principle of dependence of number of safe load cycles from the spread of distribution and the survival rate (SR). $T_N = 1$ means no scatter. The scatter increases von right (1:1) to left (1:100).
For simplification the diagram is completely based on GAUSS distribution (symmetric, normalised). Therefore lines of higher values of reliability are expected to be at lower load cycles than shown in this and the following diagrams.

Slide 3: Wöhler diagrams for Steel 42CrMo4 and CFRP as elaborated and used in:

Mair, G. W.:The Low-Cycle Fatigue of Fibre-Metal-Hybrid Structures. proceedings „Fourth International Conference on Low Cycle Fatigue and Elasto-Plastic Behaviour of Materials (LCF 4)“. Oxford: Elsevier Science 1998.

Slide 4: Rough compilation of both diagrams on slide 3 in one diagram. It shows that the low degradation of unidirectional CFRP leads to higher T_N although the scatter of tension may be lower than the one of steel.

Slide 5: Shows how to identify the necessary mean value of cycle fatigue strength based on 1000 operational fillings (green /black lines).
For $T_N = 8$ (covers a lot of metals) it is sufficient to have a mean value of 10 000 LCs (red lines). For $T_N = 50$ which may cover the CFRP a mean fatigue value of 250 000 LCs is necessary for safety of the same operational fillings (red lines). A demonstrated mean value of 10 000 as sufficient for metal liners leads to a survival rate lower than 99% (purple line).

Slide 6: Schematic diagram of degradation of reliability under operational conditions with respect to burst pressure and its dependency on the years of service life before burst test; shown for survival rates of 50 % and 99.9999%.
The safety goal to be achieved in this and the following diagrams is to demonstrate a sufficient reliability at the end of the life (necessary reliability at test pressure or at least at max developed working pressure).

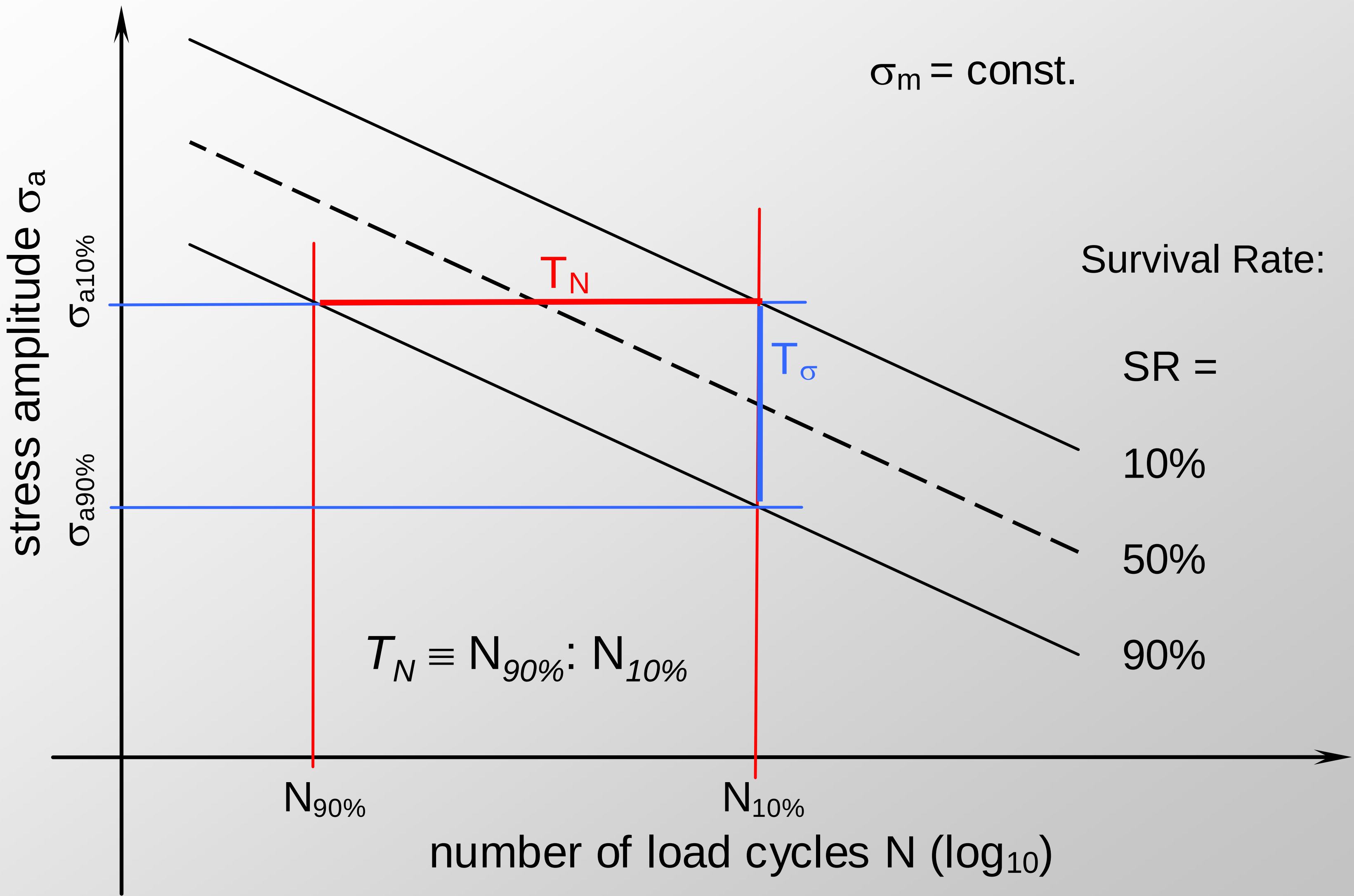
Slide 7: Schematic diagram of load cycles to failure for type III cylinder (designed for limited life of 15 years) and a type IV cylinder (designed for 30 years).

Slide 8: Schematic diagram of linear degradation under stress rupture conditions (time to burst at given pressure level).

Slide 9: Schematic diagram of stress rupture testing with assumed test results (red dots). Composed of one set of rapid burst test (e. g. 100 bars/min) and two sets of tests at lower pressure levels (time to burst under sustained pressure). This kind of degradation is predicated as being covered conservatively by stress ratios
Currently BAM runs a test program which shall show whether the pressure level 1 in the diagram can be substituted by very slow rapid burst tests (e. g. 1 bar/min). This would reduce the test effort enormously. By performing those tests the use of general stress rations seams to be redundant.

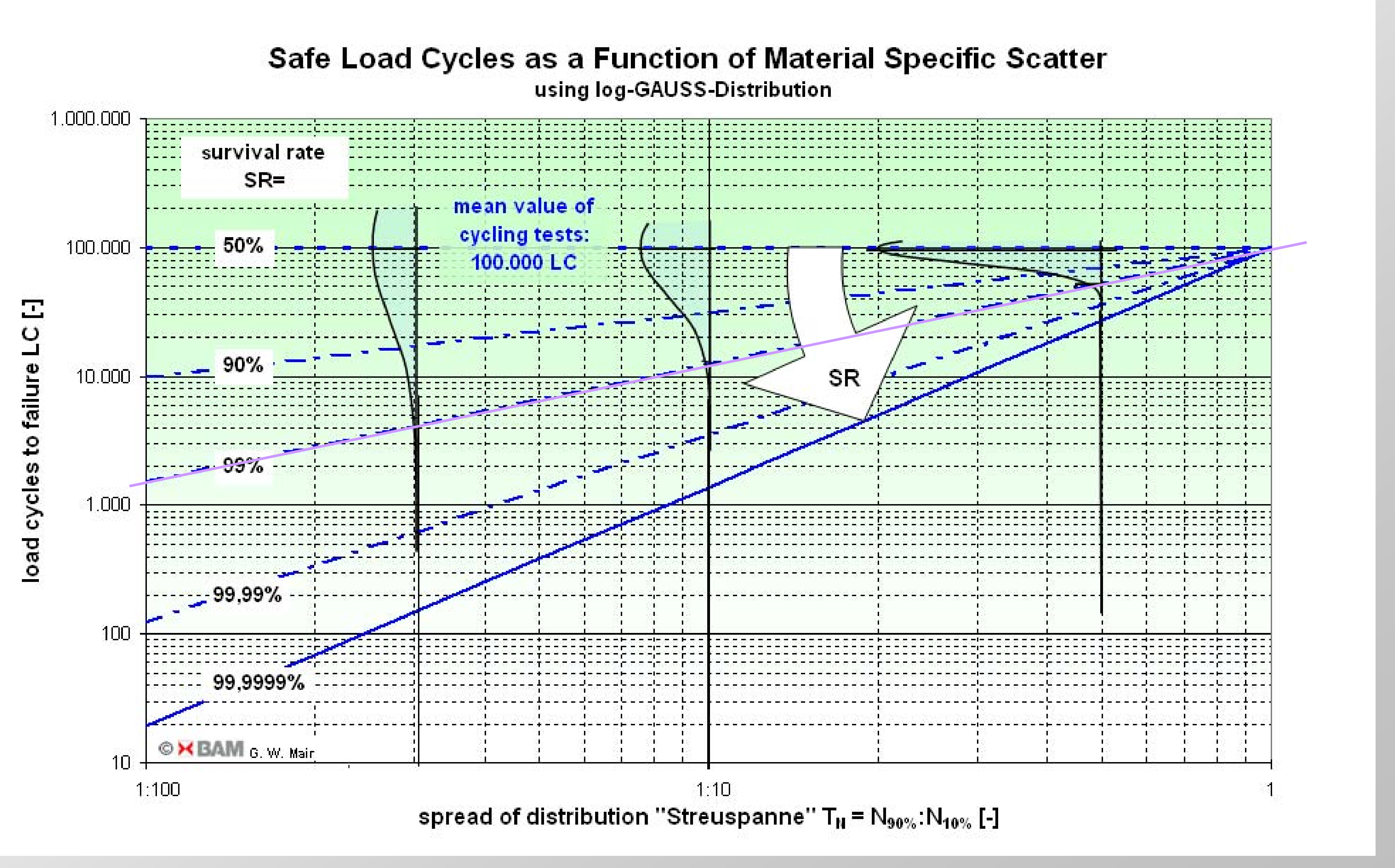
Annex: 9 Slides

Definition of „Streuspanne“ T_N

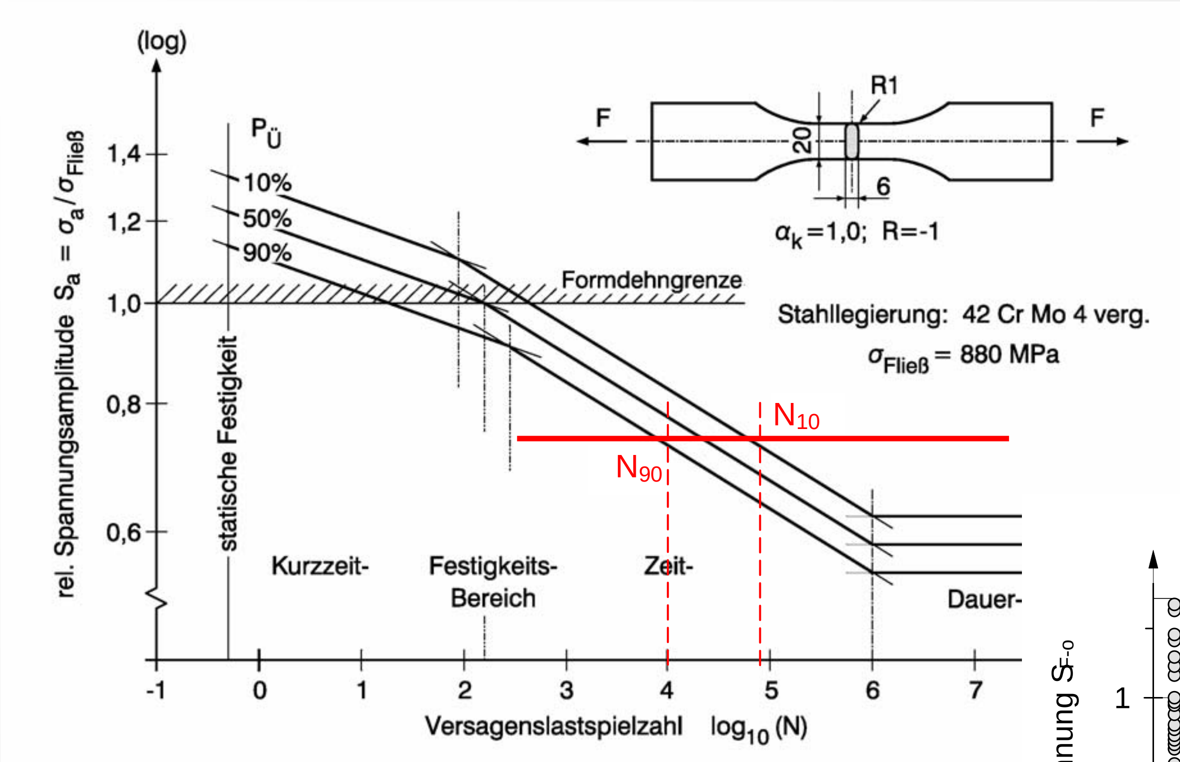


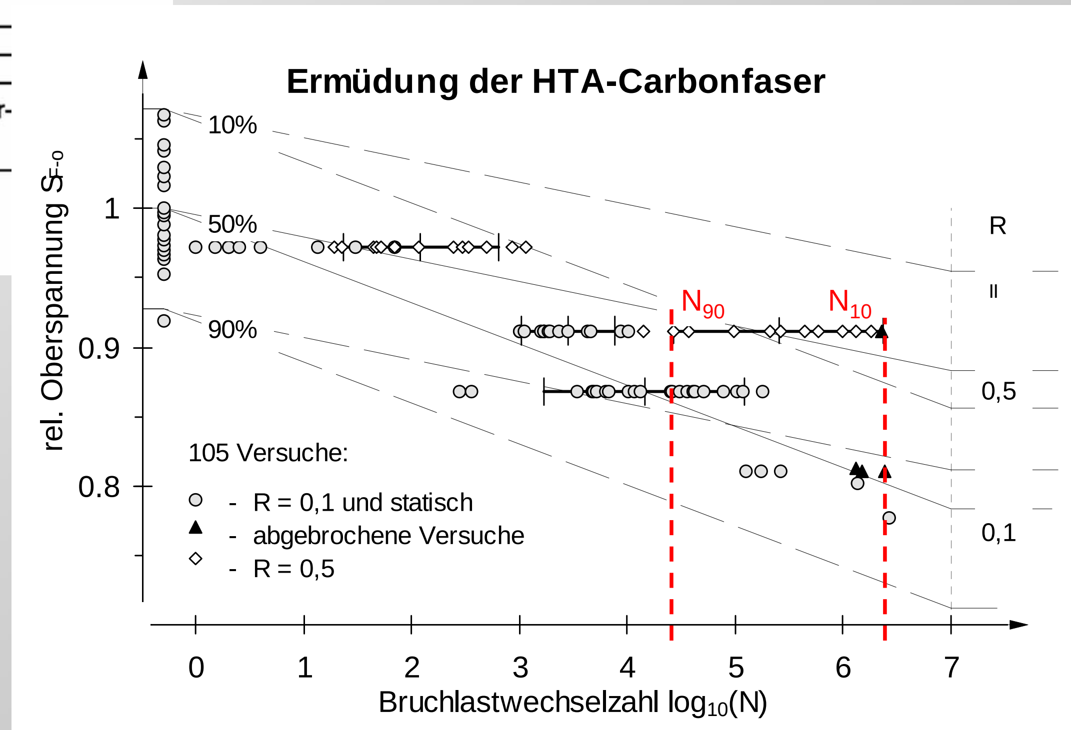
Test Methods: Fatigue Scatter

Fachgruppe III.2- Dr. G. W. Mair



Test Methods: Fatigue Scatter

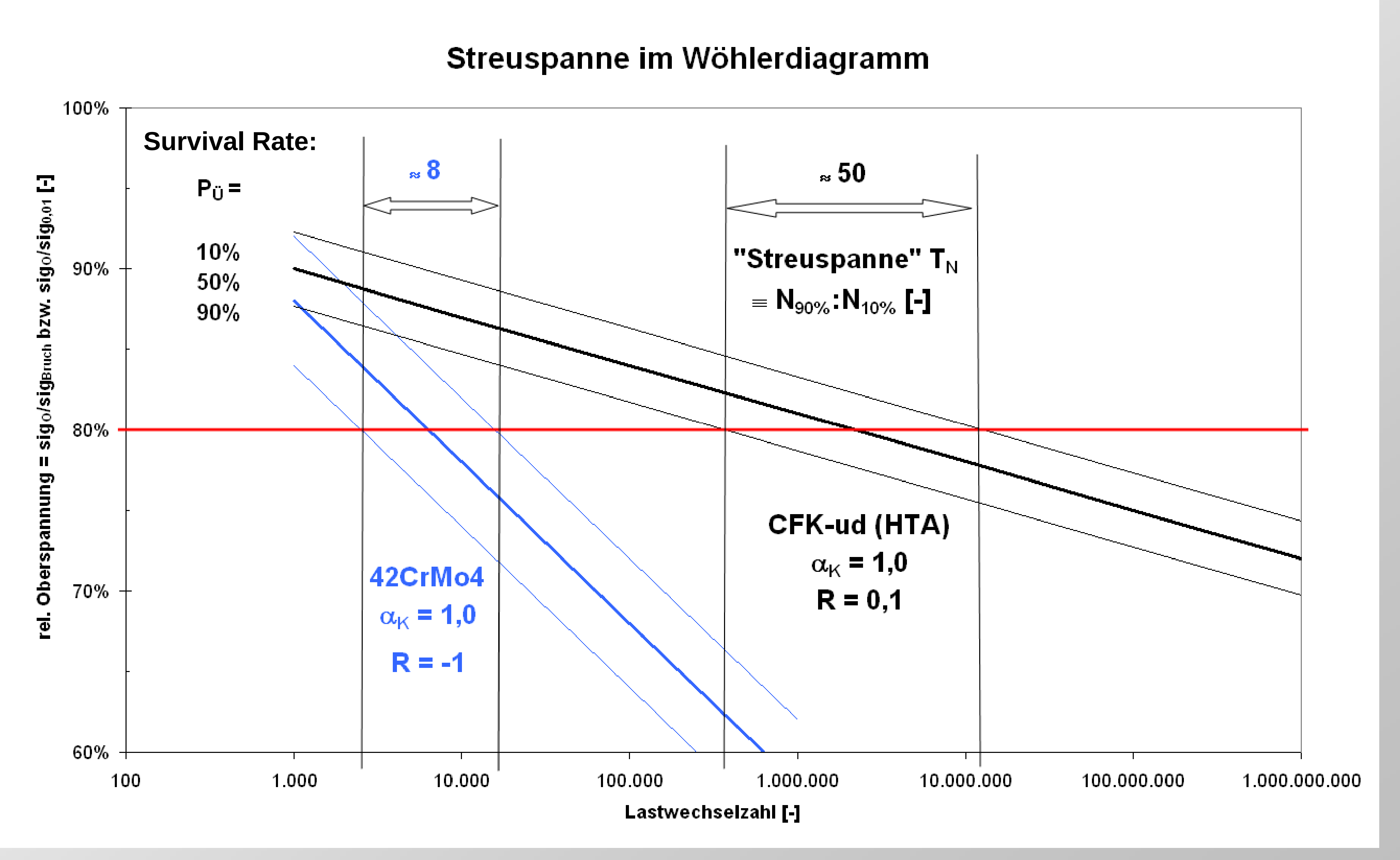




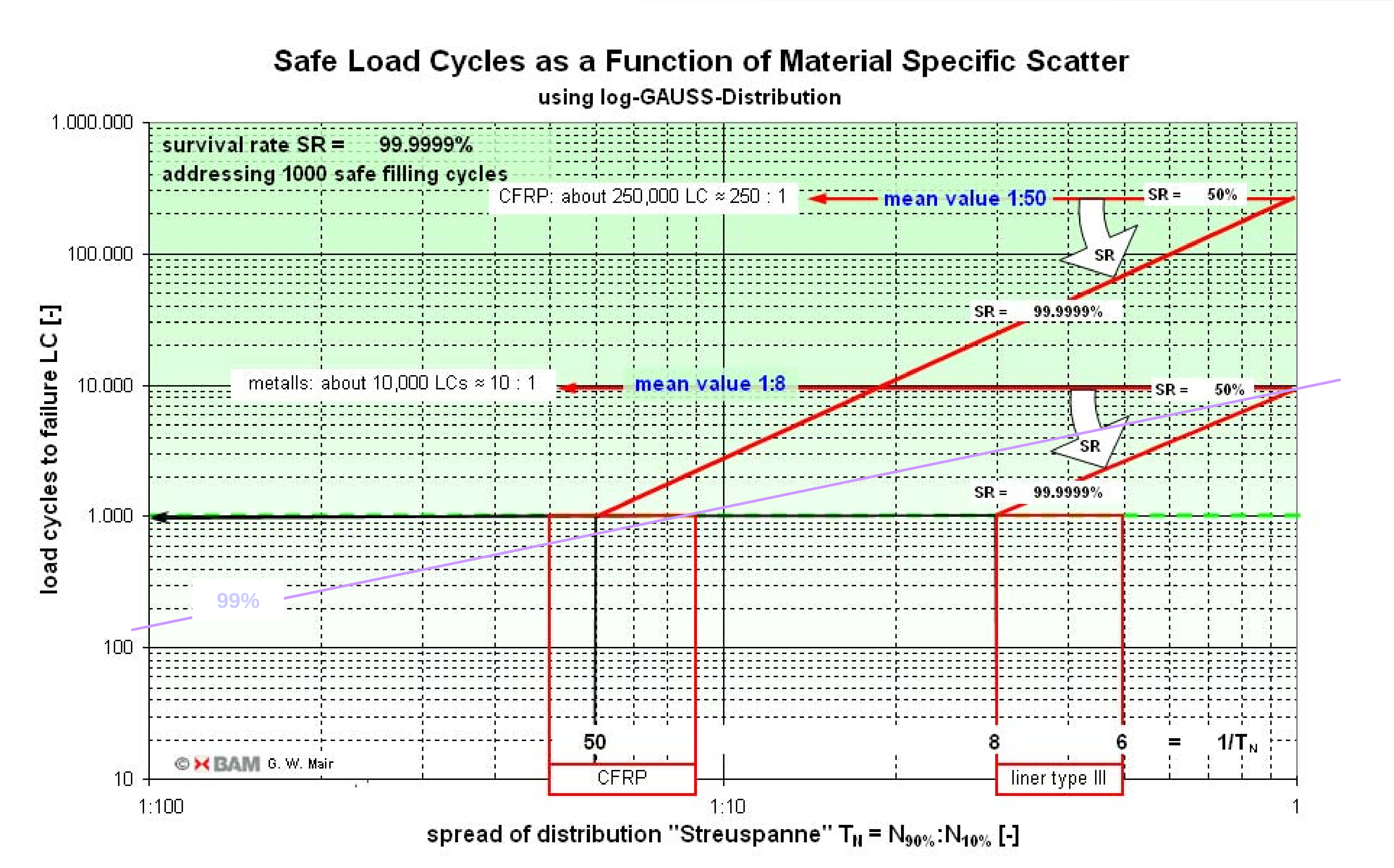
Excuse the use of
diagrams in German

Test Methods: Fatigue Scatter

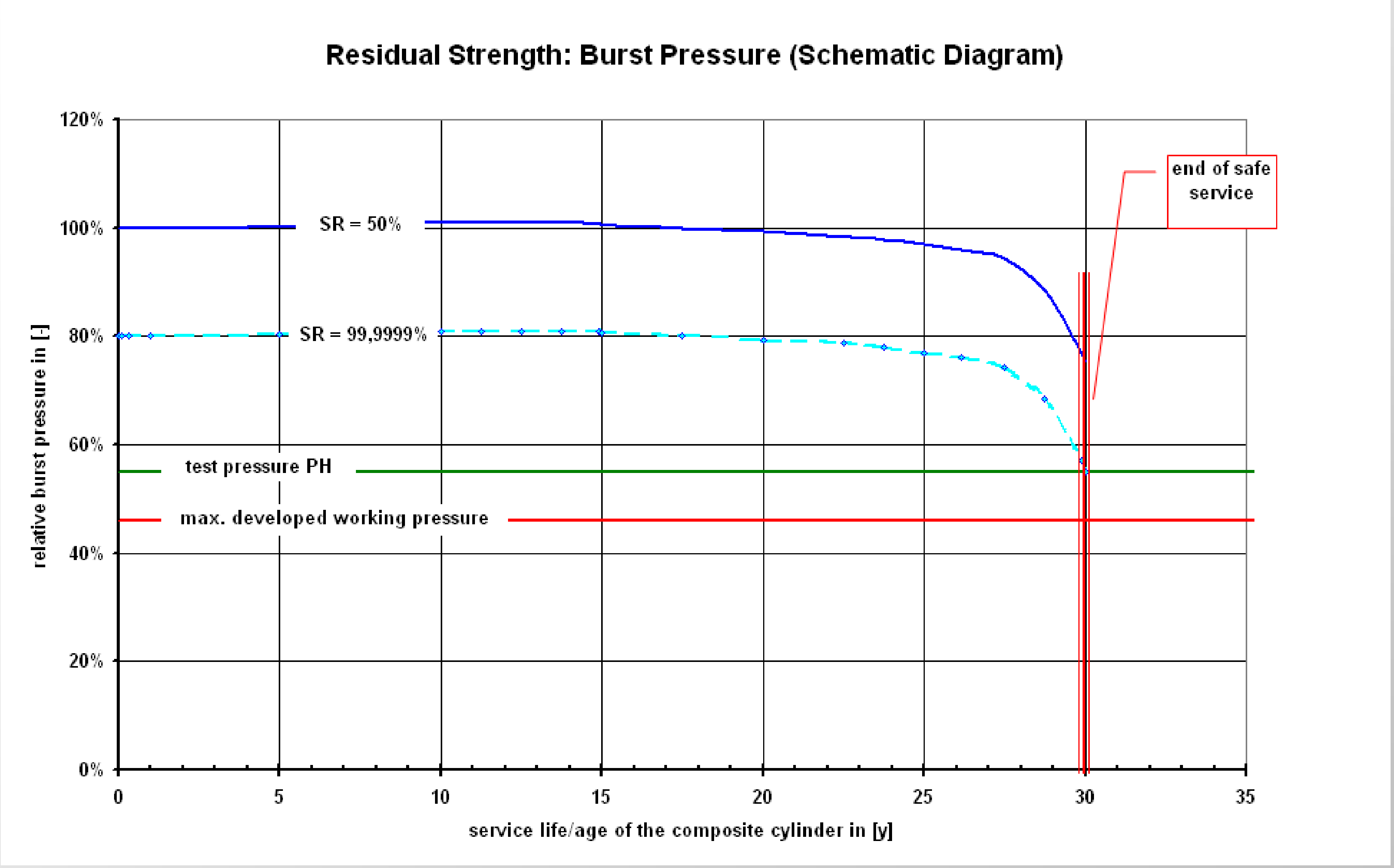
Fachgruppe III.2- Dr. G. W. Mair



Test Methods: Fatigue Scatter

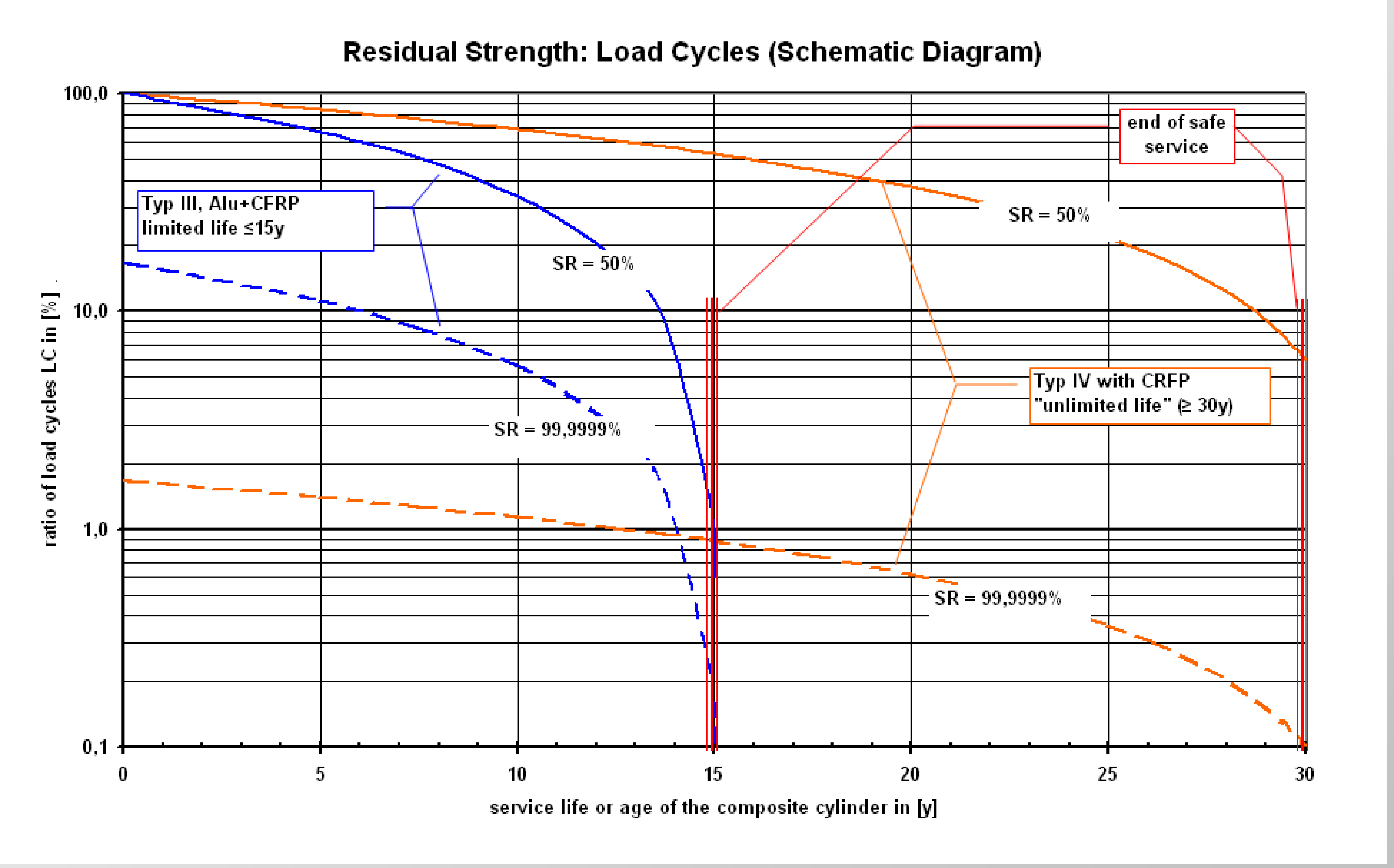


Test Method: Burst Test



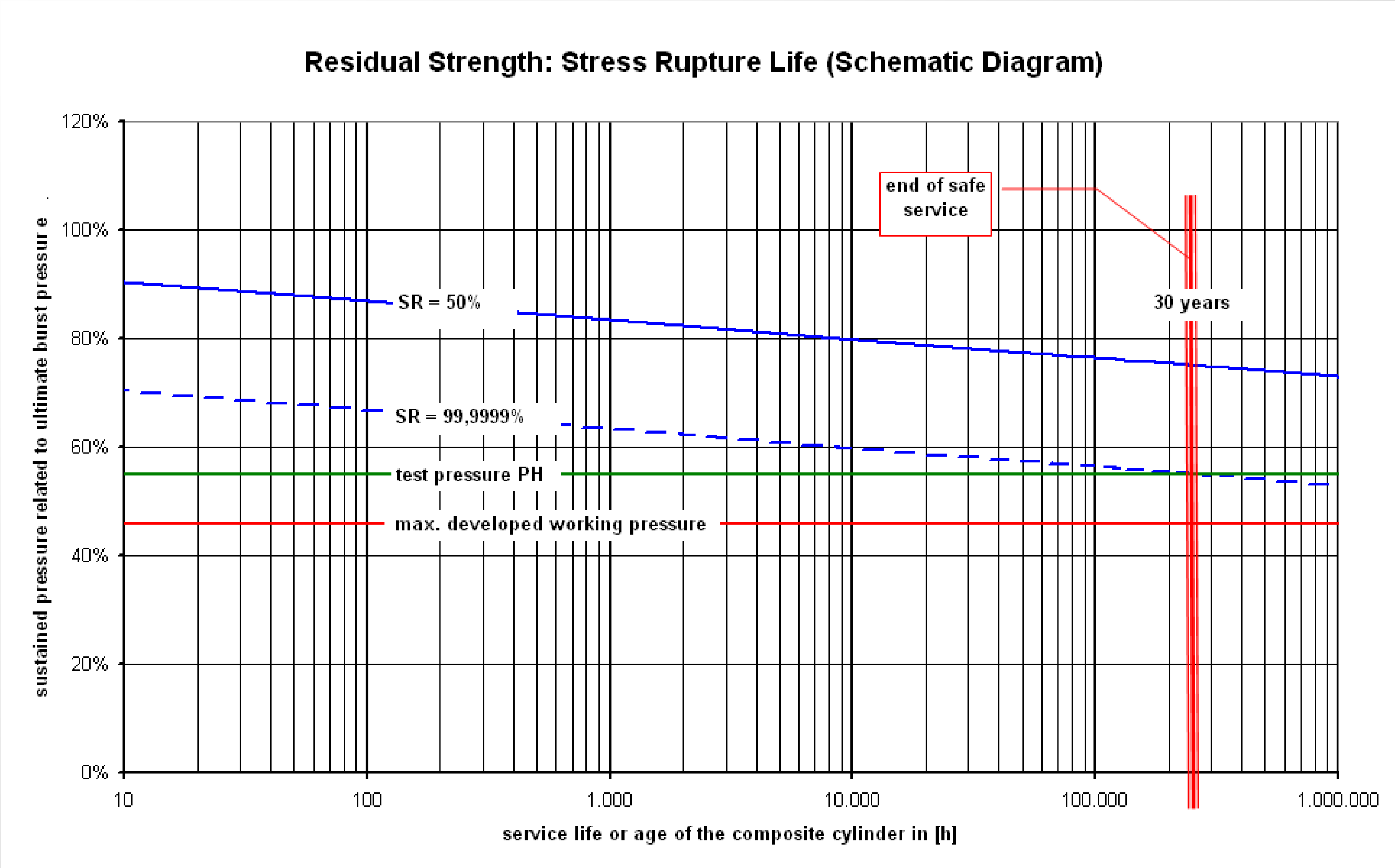
The burst pressure shows often an increase during service life and a late decrease.

Test Method: Pressure Cycling



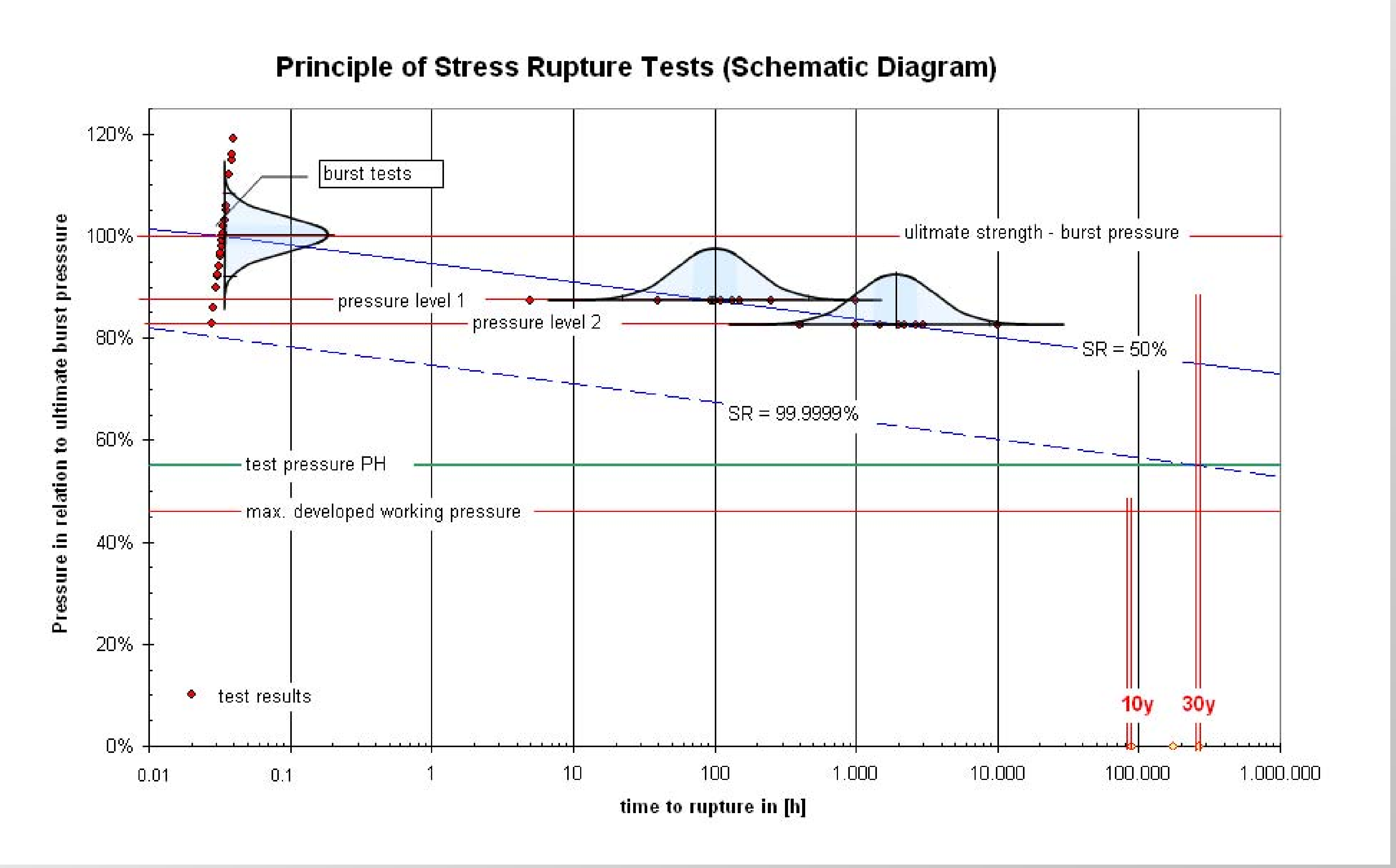
The load cycles to failure are expected to degrade linear during service life.

Test Method: Sustained Load Test



The sustained stress rupture life have to be extrapolated by tests shorter than 2000 h.

Proposal: Stress Rupture Testing



In 2009 and 2010 BAM has run a test series for reduction of effort to minimum.