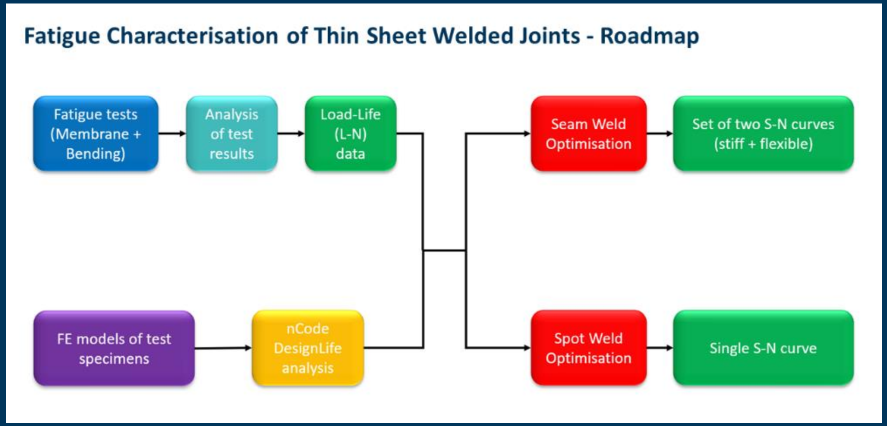
Virtual Seminar Series – Tuesday 2, 9, 16 November



Fatigue Characterisation of Welded Joints

Presented by Dr. Cristian Bagni
Prenscia (HBK)

Tuesday, November 16, 2021

Fatigue Characterisation of Welded Joints

Abstract

Previous presentations have introduced finite element modelling techniques for structural stress based fatigue life prediction of welds, fatigue test specimen design, and failure mode validation for fatigue tests of spot welded and seam welded joints. The immediately preceding presentation has described fatigue testing and characterisation of the fatigue performance of a material with statistical reliability and confidence.

This presentation describes post processing of welded joint fatigue test measurements to determine the number of cycles to failure for an appropriate failure criterion. It then illustrates the consequent characterisation of the fatigue performance of the joint, where:

- The characterisation for spot welds requires optimising the factors in the structural stress equation to collapse two load-life curves, from membrane dominated and bending-dominated fatigue tests, into a single stress-life curve.
- The characterisation for seam welds requires isolating membrane and bending components from two load-life curves, again from membrane dominated and bending-dominated fatigue tests, to generate a set of two stress-life curves, one to represent wholly membrane stress and the other pure bending stress.

About the presenter, Dr. Cristian Bagni, Prenscia (HBK)

Dr. Cristian Bagni holds a Master’s Degree in Civil and Structural Engineering (Unversità degli Studi di Parma, Italy) and a PhD in Structural Engineering (The University of Sheffield) developing a new Finite Element methodology to assess the static and fatigue behaviour of notched and cracked components.

He has written publications on Computational Mechanics and Fatigue and he has been reviewer for the following International Journals: Fatigue & Fracture of Engineering Materials & Structures (FFEMS) and Theoretical and Applied Fracture Mechanics.

After having worked for years at the University of Sheffield’s Advanced Manufacturing Research Centre (AMRC) on high profile aerospace research projects, he has also gained extensive experience on advanced manufacturing processes.

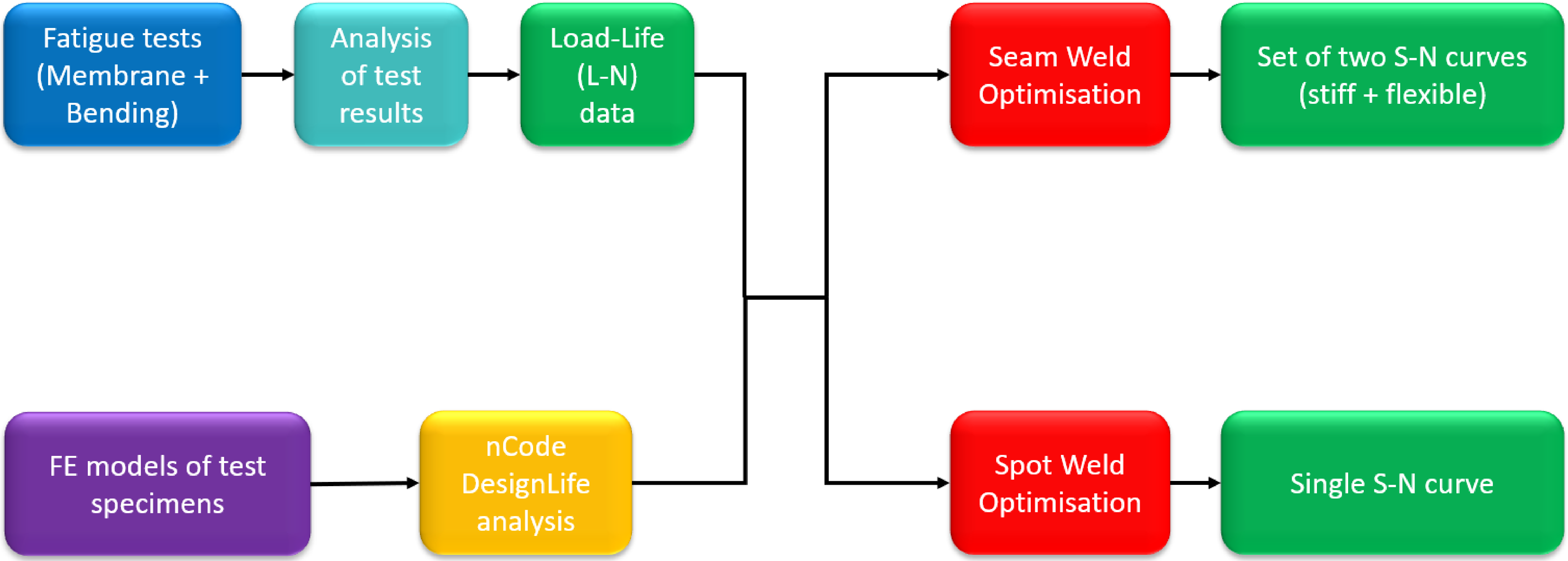
Cristian joined HBK in July 2020 as Technologist for Fatigue and Fracture and amongst his activities he is supporting the Advanced Materials Characterisation & Testing (AMCT) facility with the analysis and post-processing of fatigue test results and consequent characterisation of the fatigue performance of welded components.

Fatigue Characterisation of Thin Sheet Welded Joints

Dr Cristian Bagni

16th November 2021

Fatigue Characterisation of Thin Sheet Welded Joints - Roadmap



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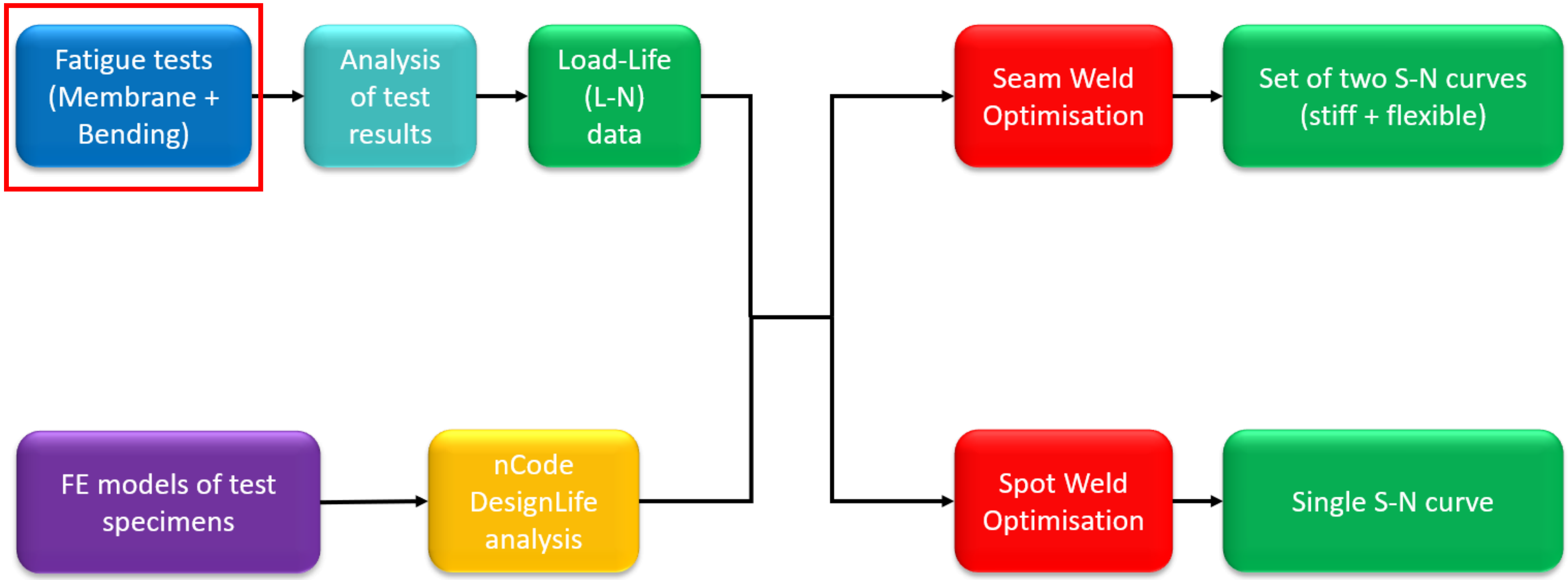
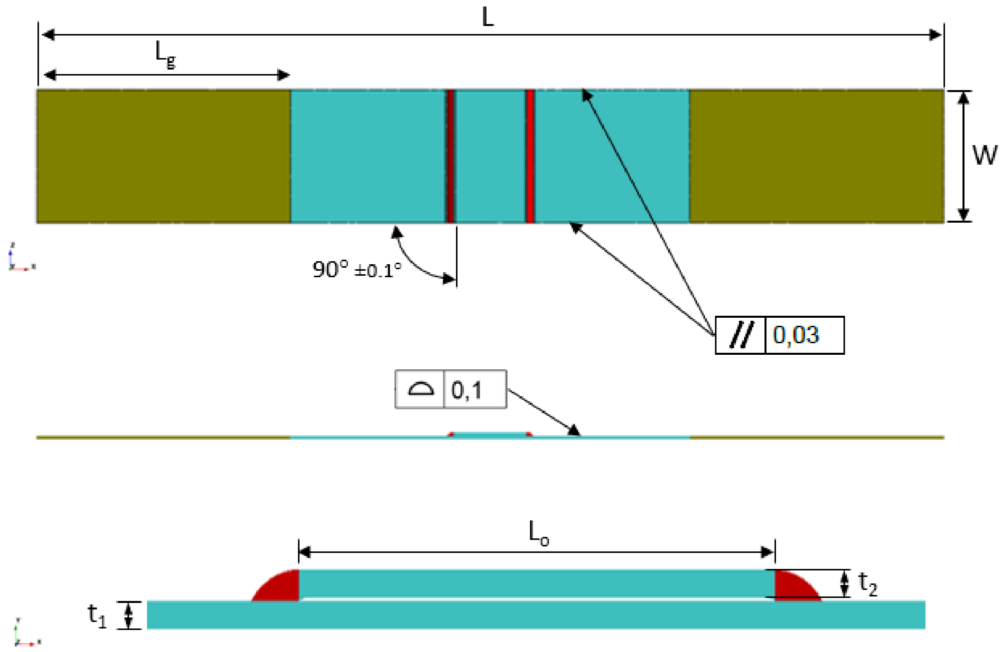
Agenda

- Fatigue Tests
- Analysis of the Fatigue Test Results
- Load-Life (L-N) data
- Finite Element Models of the Test Specimens & nCode DesignLife Analysis
- Optimisation and S-N curves generation – Seam Welds
- Optimisation and S-N curves generation – Spot Welds
- Q & A

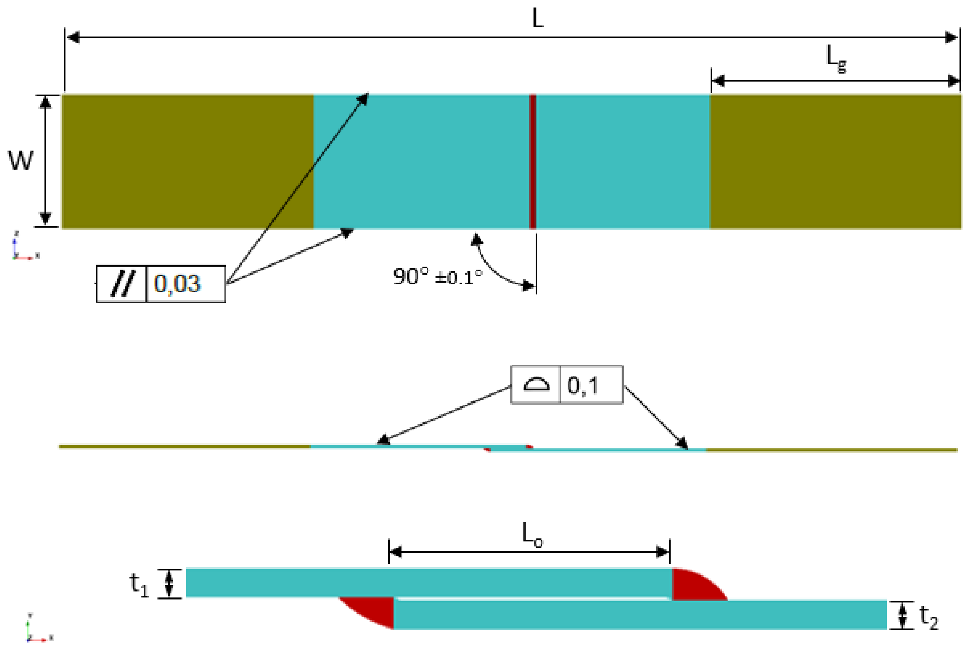
Fatigue Tests



Fatigue Tests – Example of test specimens (Seam Welds)



Membrane



Bending

- Membrane specimens → Bending ratio usually $0.05 \leq r \leq 0.2$
- Bending specimens → Bending ratio $r \geq 0.7$
- Failure expected at the weld toe (FE simulation + DesignLife analysis is needed to verify this).
- Fatigue performance is strongly influenced by thickness and quality of the welds.
- Material (including heat treatments, surface roughness, coatings, etc.), thickness and welding process must be representative of those used in production.

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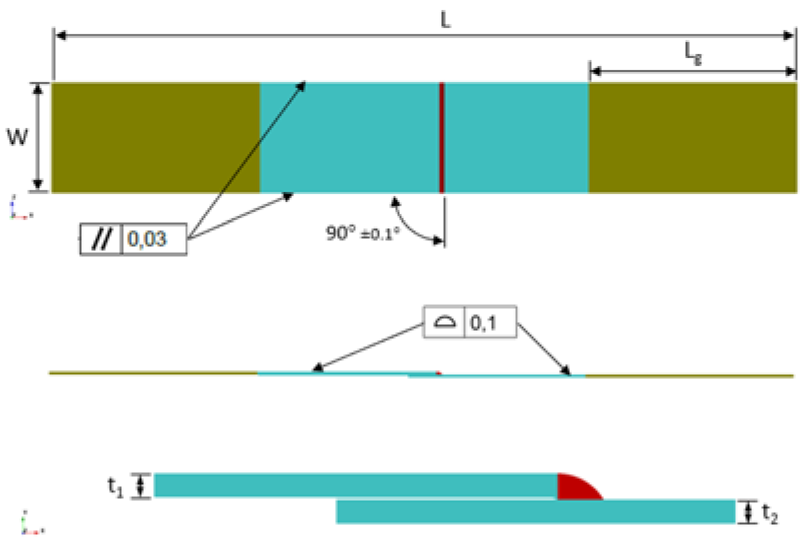
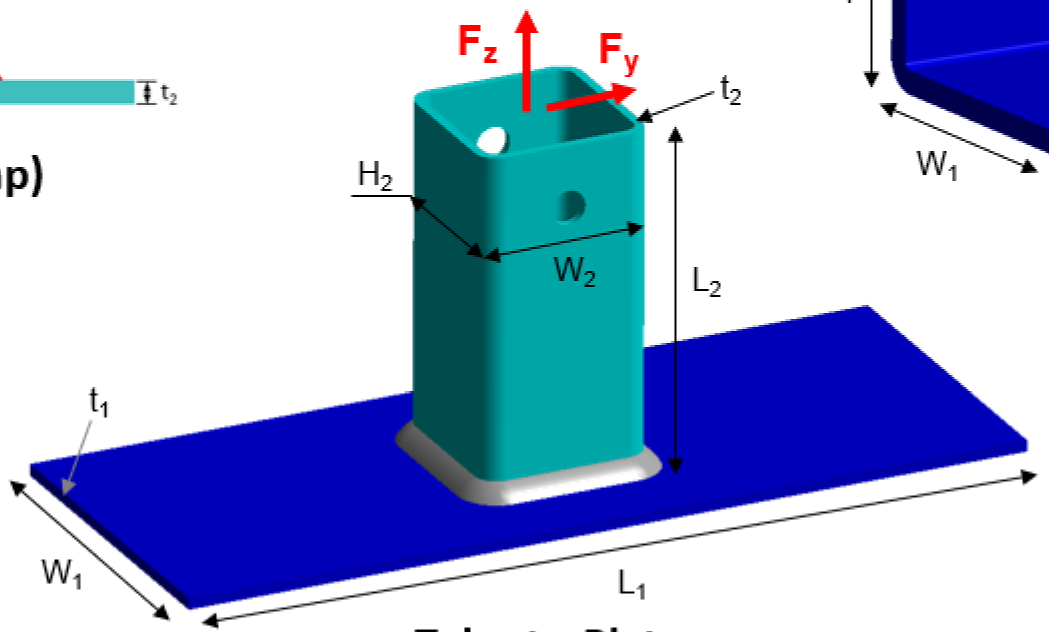
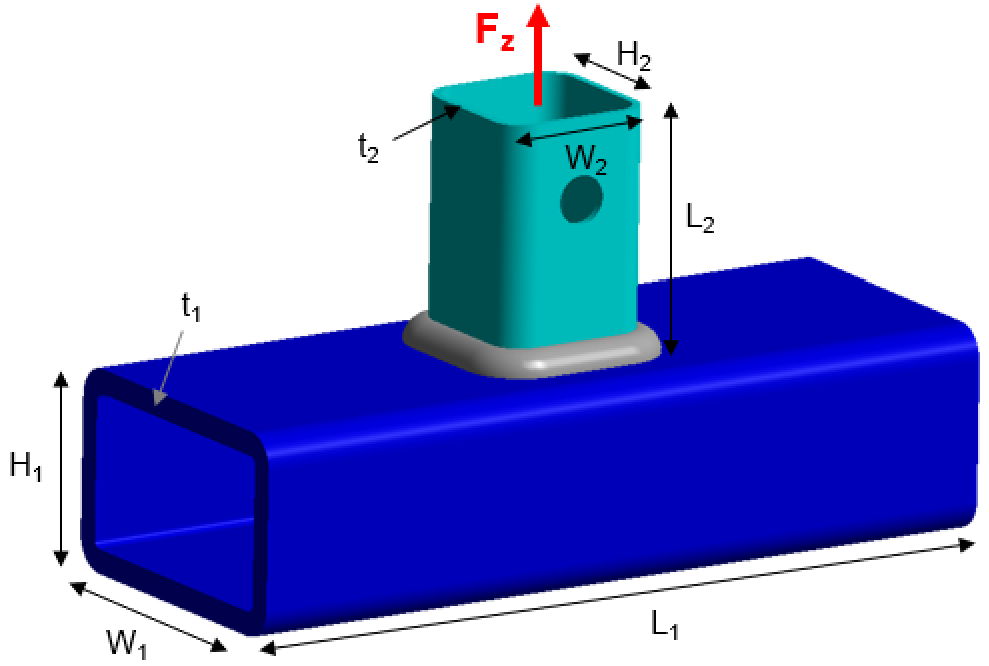
Fatigue Tests – Other specimen geometries (Seam Welds)



Bending (single weld overlap)



Tube-to-Plate



Tube-to-Tube

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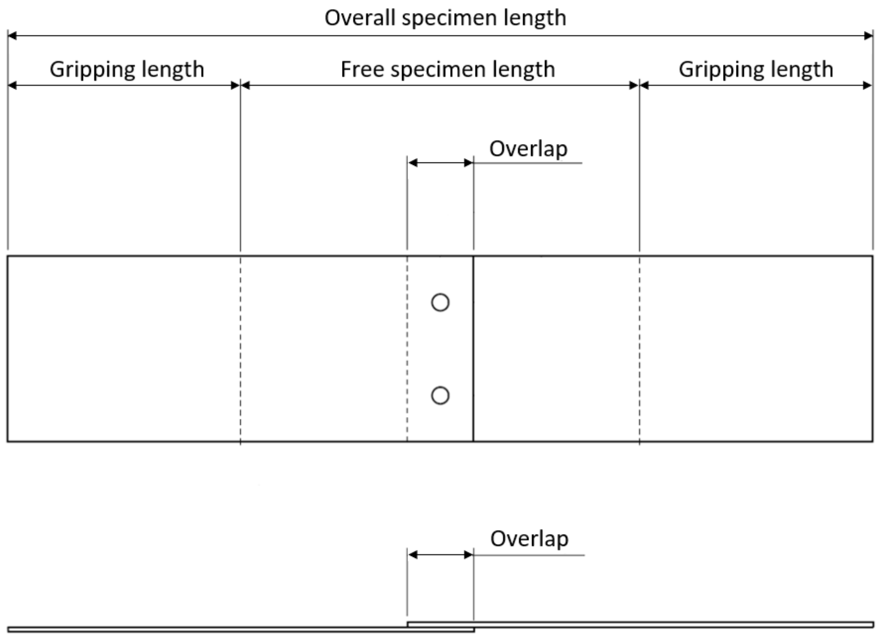
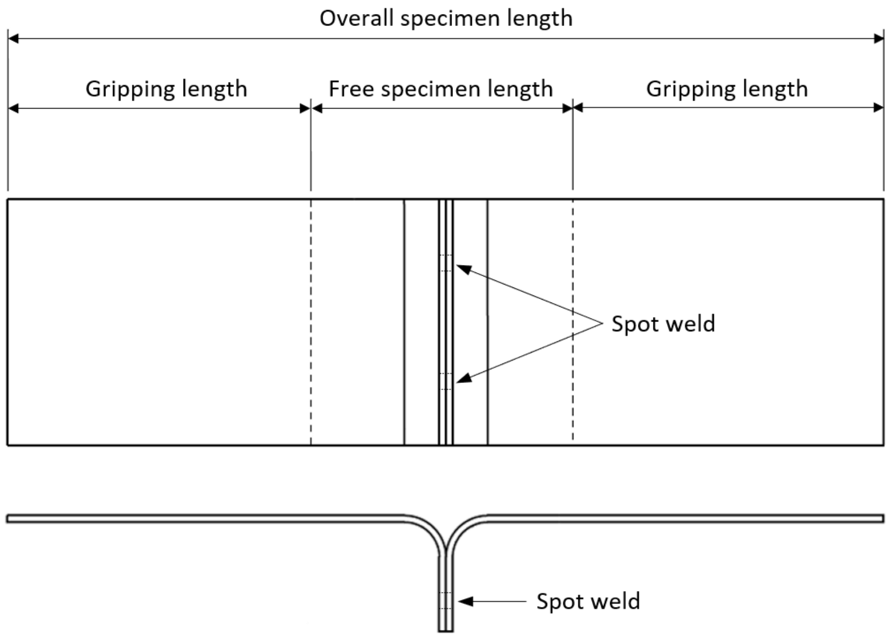
Fatigue Tests – Example of test specimens (Spot Welds)



Lap Shear (Membrane)

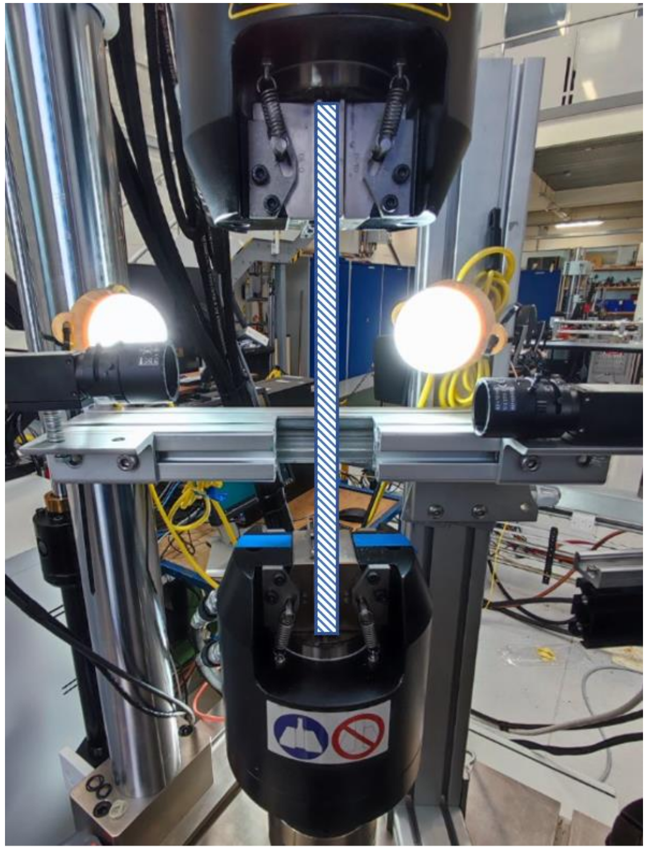


Coach Peel (Bending)

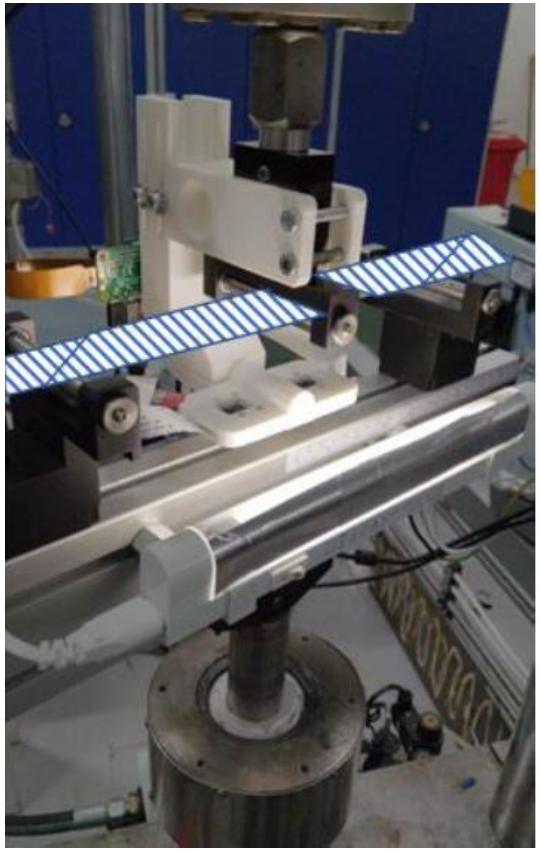
- Fatigue performance is strongly influenced by thickness and quality of the welds.
- Material (including heat treatments, surface roughness, coatings, etc.), thickness and welding process must be representative of those used in production.

Fatigue Tests – Examples of test set-up

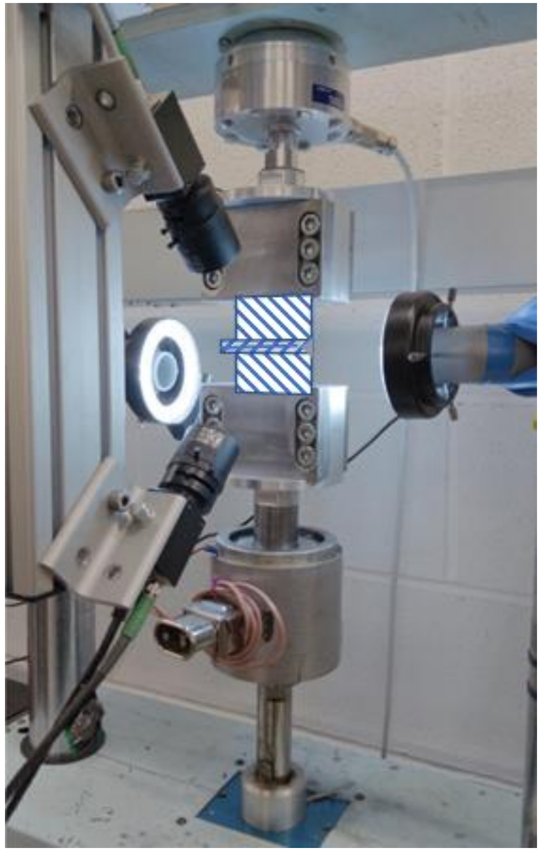
Seam Weld
Membrane Specimen



Seam Weld
Bending Specimen



Seam Weld
3-point Bending



Spot Weld
Coach Peel Specimens

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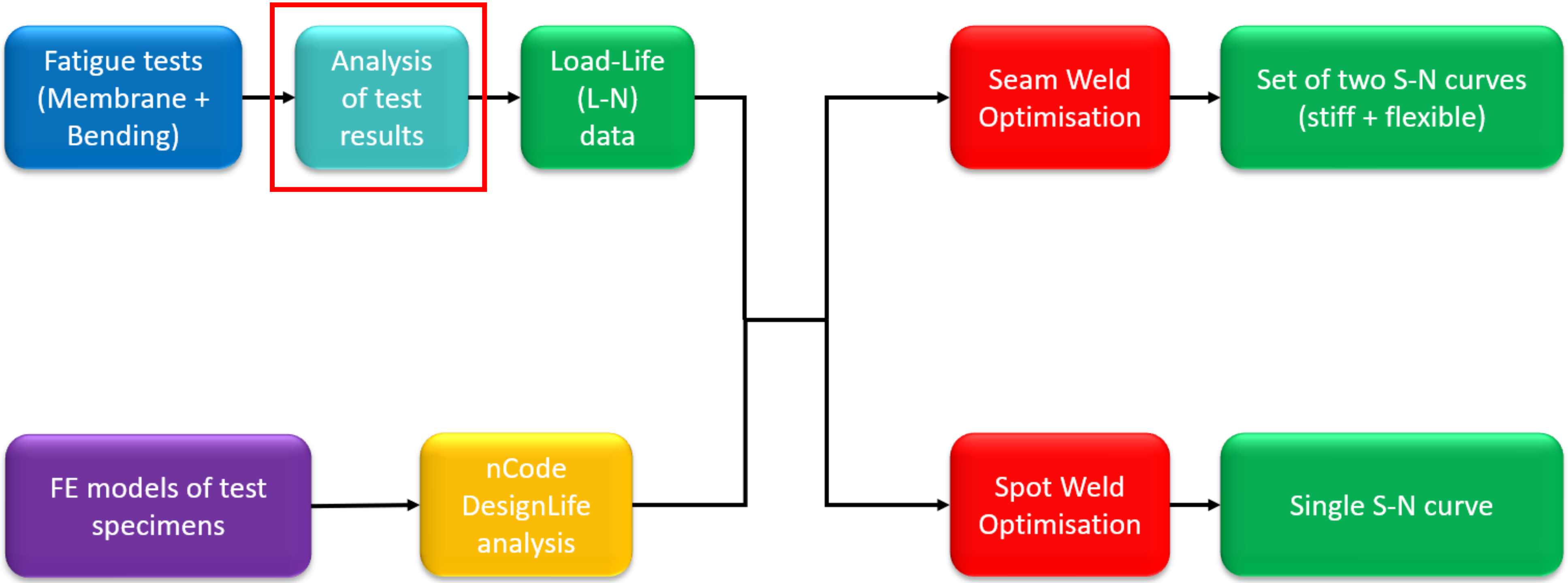
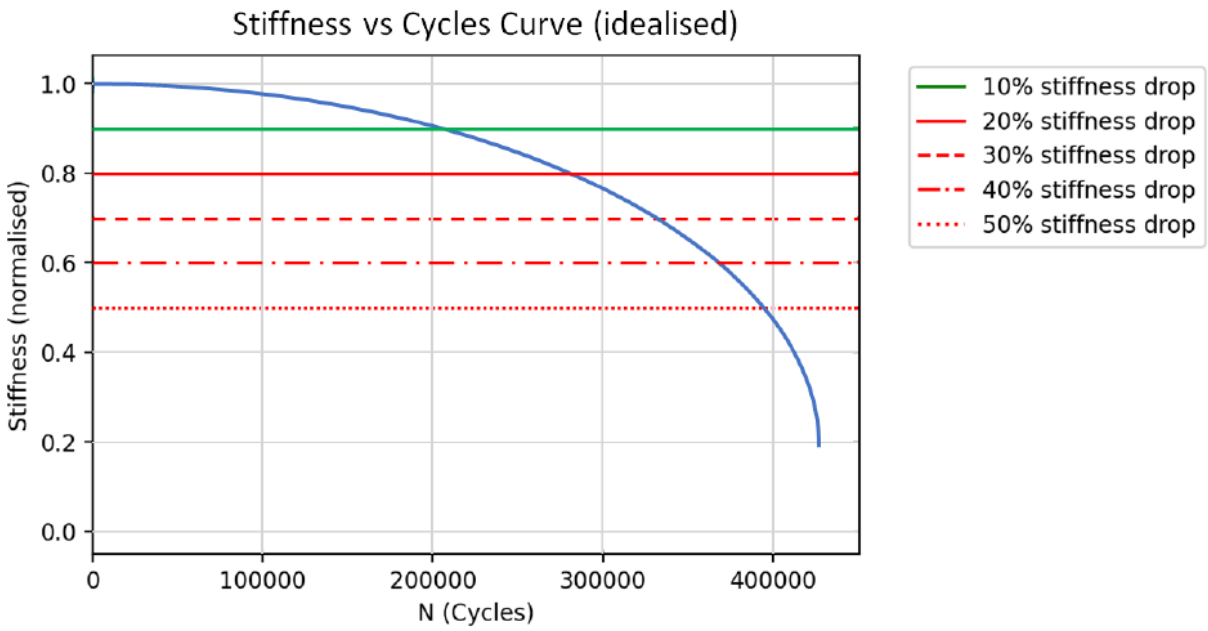
Analysis of the Fatigue Test Results

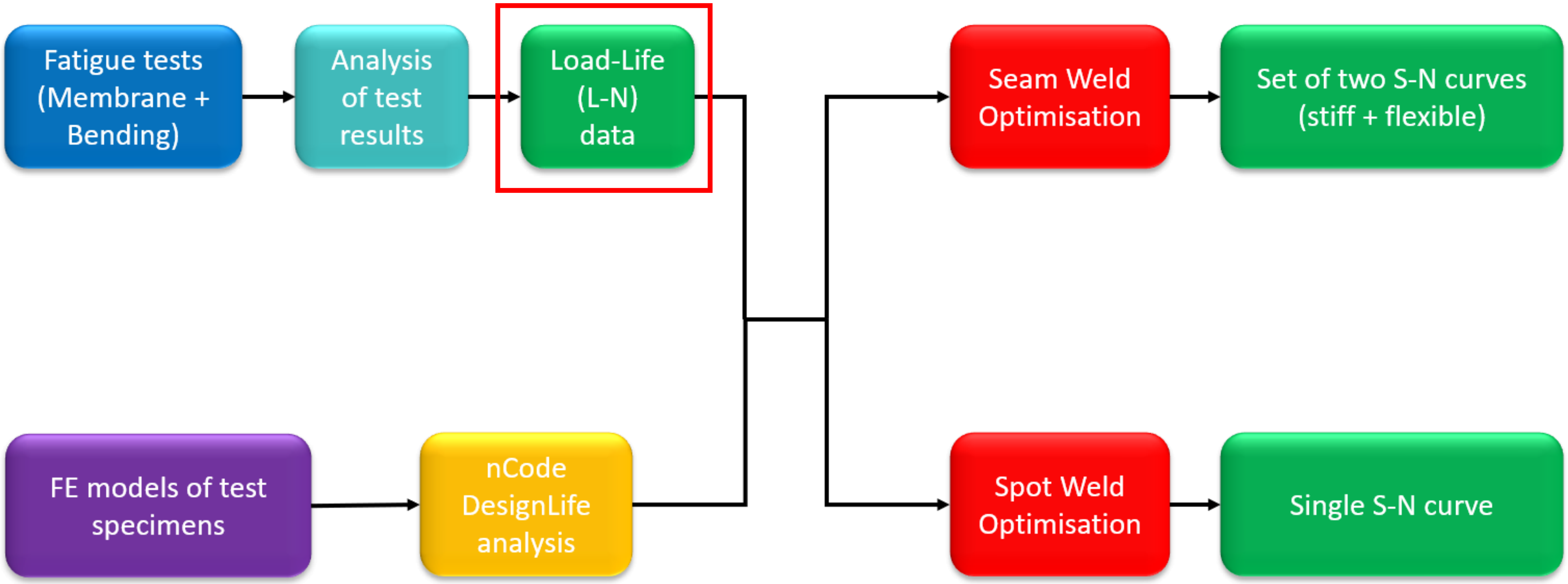


Analysis of the test results

- Stiffness at each cycle normalised respect to the stiffness at a given number of cycles chosen so that:
  - The cyclic load is stable and at the target load;
  - The stiffness is not decreasing due to the propagating fatigue crack.
- Cycles to failure determined based on a chosen failure criterion, e.g.:
  - Separation;
  - Stiffness drop;
  - Combination of the two.
- Review recording of tests to verify test, location of crack initiation and cycles to first visible crack.



Load-Life (L-N) data



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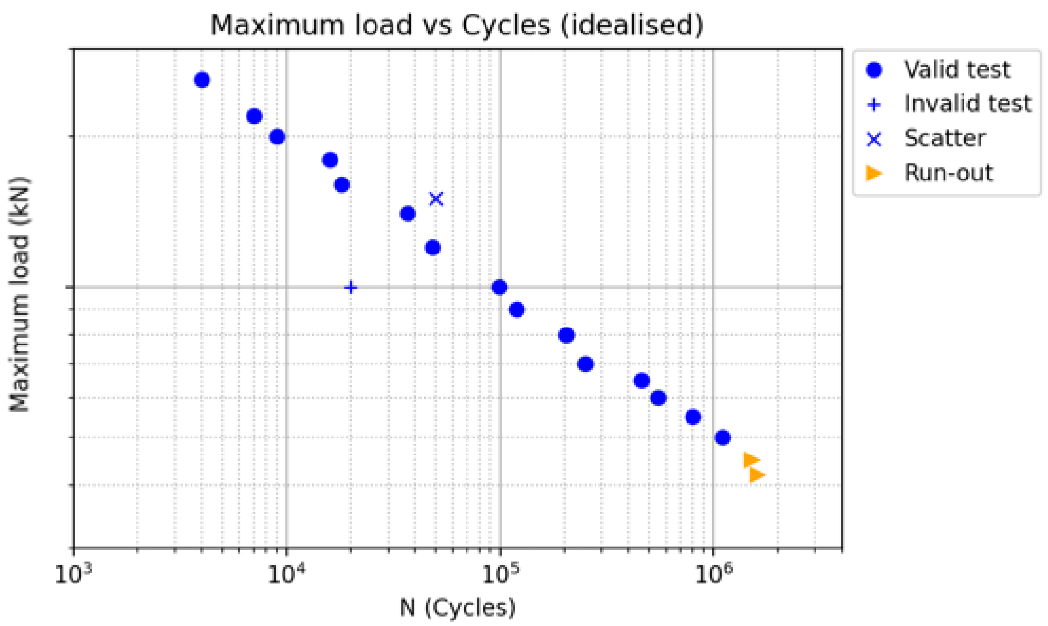
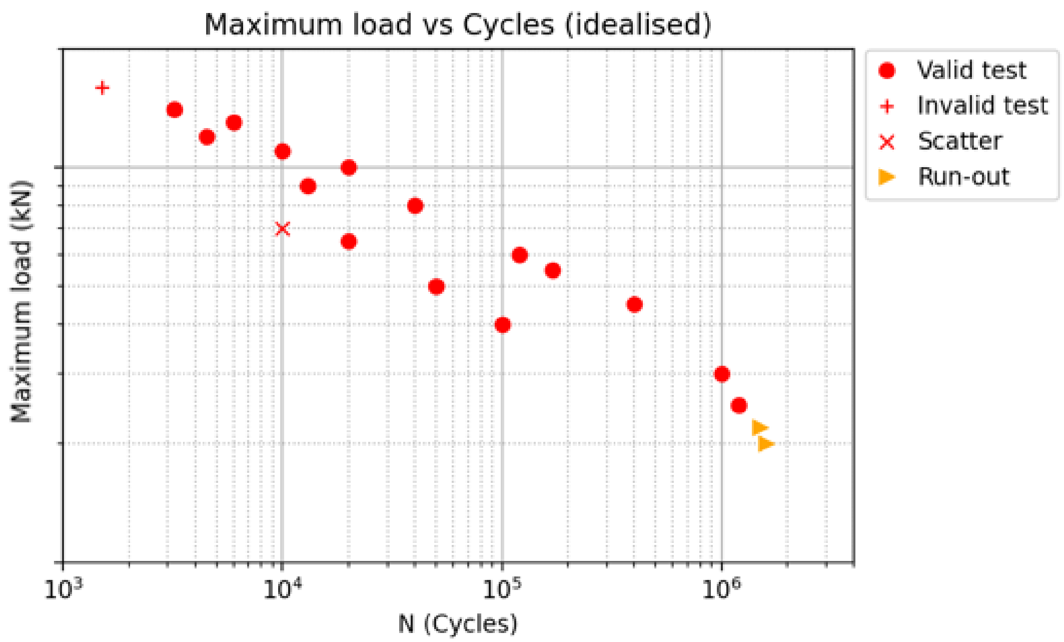
Load-Life (L-N) data and plots



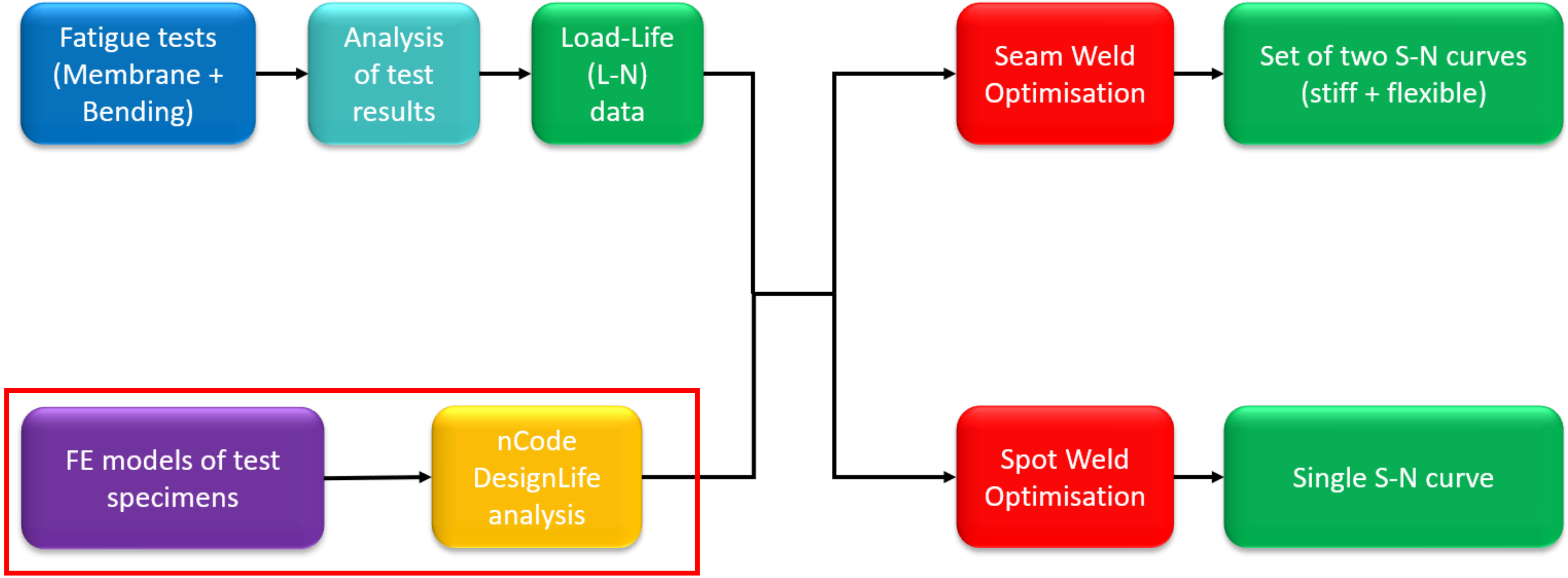
Membrane



Bending

- Run-out tests are valid tests. However, the corresponding datapoints cannot be used in the generation of the S-N curves.
- Excluded points refer to test rig failures. The corresponding datapoints cannot be used in the generation of the S-N curves.
- Scatter points refer to test where something unusual happened. It is up to the users' judgement if to use these points in the generation of the S-N curves or not.
- Poor quality welds/specimens might introduce a large amount of scatter.

Finite Element Models of the Test Specimens & nCode DesignLife Analysis



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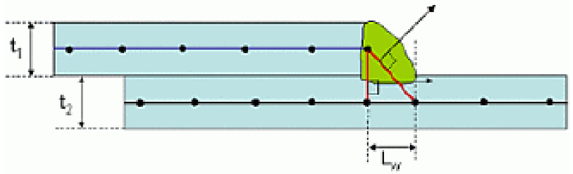
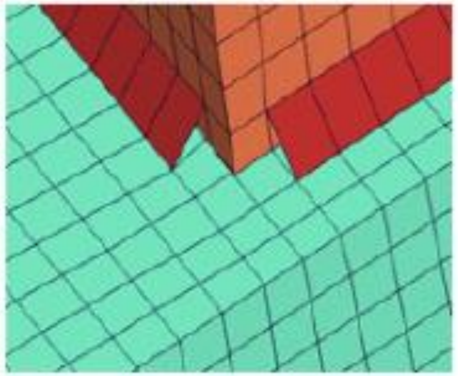
Finite Element Models

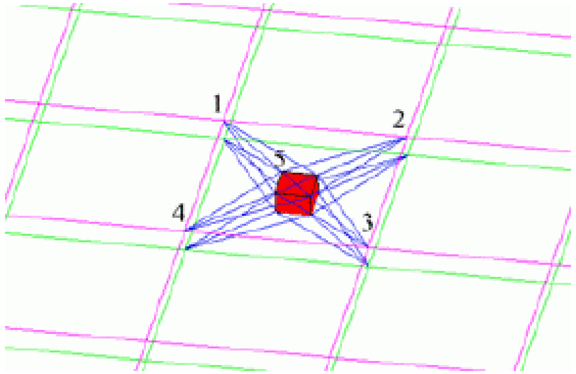
- The FE models are generated:
  - using the preferred FE software and modelling strategies used to model the production components;
  - following the modelling guidelines included in the DesignLife Theory Guide;
  - based on the nominal sizes of the test specimens (if the actual thickness of the specimens differs significantly from the nominal value, the FE models should be modified to reflect the actual thickness);
  - applying a unit load (e.g., 1 kN).
- The output of the FE analysis needed as input of the analysis in nCode DesignLife are the nodal forces and moments.



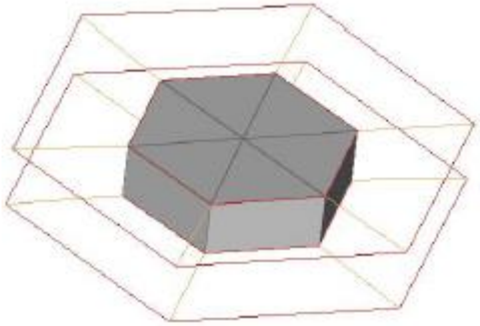
Seam Weld – Overlap



Seam Weld – Fillet



Spot Weld – Area Contact Methods



Spot Weld – PENTA Elements

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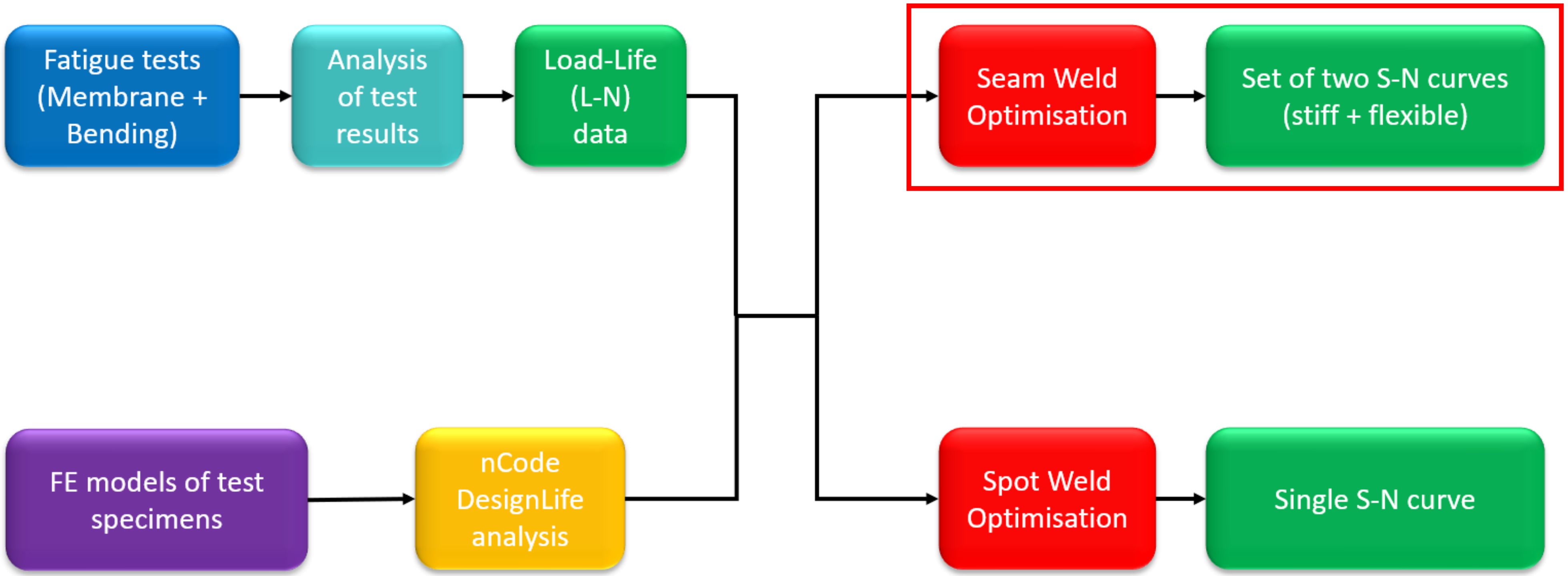
nCode DesignLife Analysis

- Both membrane and bending specimens are analysed in DesignLife
  - At each load level used in the fatigue tests
  - Using the FE models described in the previous slide as input.
- For each load level and for each element of the FE model the analysis estimates:
  - Stresses
  - Bending ratio
  - Damage
  - Life
  - etc.
- We are interested in the element with the highest damage (or shortest life).
- More information on how to set up an analysis for seam welds and spot welds in nCode DesignLife can be found in the DesignLife Theory Guide.

Optimisation and S-N curves generation
– Seam Welds –



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Optimisation and S-N curves generation

- For both membrane and bending specimens at each load level, the error between the predicted life of the most damaged element , N_{fp}, and the life resulting from the test, N_{fp}, is calculated:
  - E = N_{fp} / N_{ft}
  - Weighted error.
- N_{fp} can be the one determined through nCode DesignLife or it can be calculated starting from the maximum and minimum stresses determined by nCode DesignLife:

$$N_{fp} = \left(\frac{\Delta\tilde{\sigma}}{SRI1_{int}}\right)^{1/b1_{int}}$$

where $\Delta\tilde{\sigma}$ is the “thickness corrected” stress range, $SRI1_{int}$ is the interpolated stress range intercept and $b1_{int}$ is the interpolated first fatigue strength exponent (see DesignLife Theory Guide for more information).

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Optimisation and S-N curves generation

- The following three S-N curve parameters are varied to minimise the sum of the errors previously calculated:
  - First fatigue strength exponent of the flexible S-N curve (r = 1), $b1_{flex}$ (often it is assumed $b1_{flex} = b1_{stiff}$)
  - Intercept of the flexible S-N curve (r = 1), $SRI1_{flex}$
  - Intercept of the stiff S-N curve (r = 0), $SRI1_{stiff}$ (with $SRI1_{stiff} \leq SRI1_{flex}$)
- The optimization can be performed in different ways, based on the user's preference:
  - Excel spreadsheet
  - Running nCode DesignLife in batches together with an external optimiser
  - Dedicated code (e.g., in Python)

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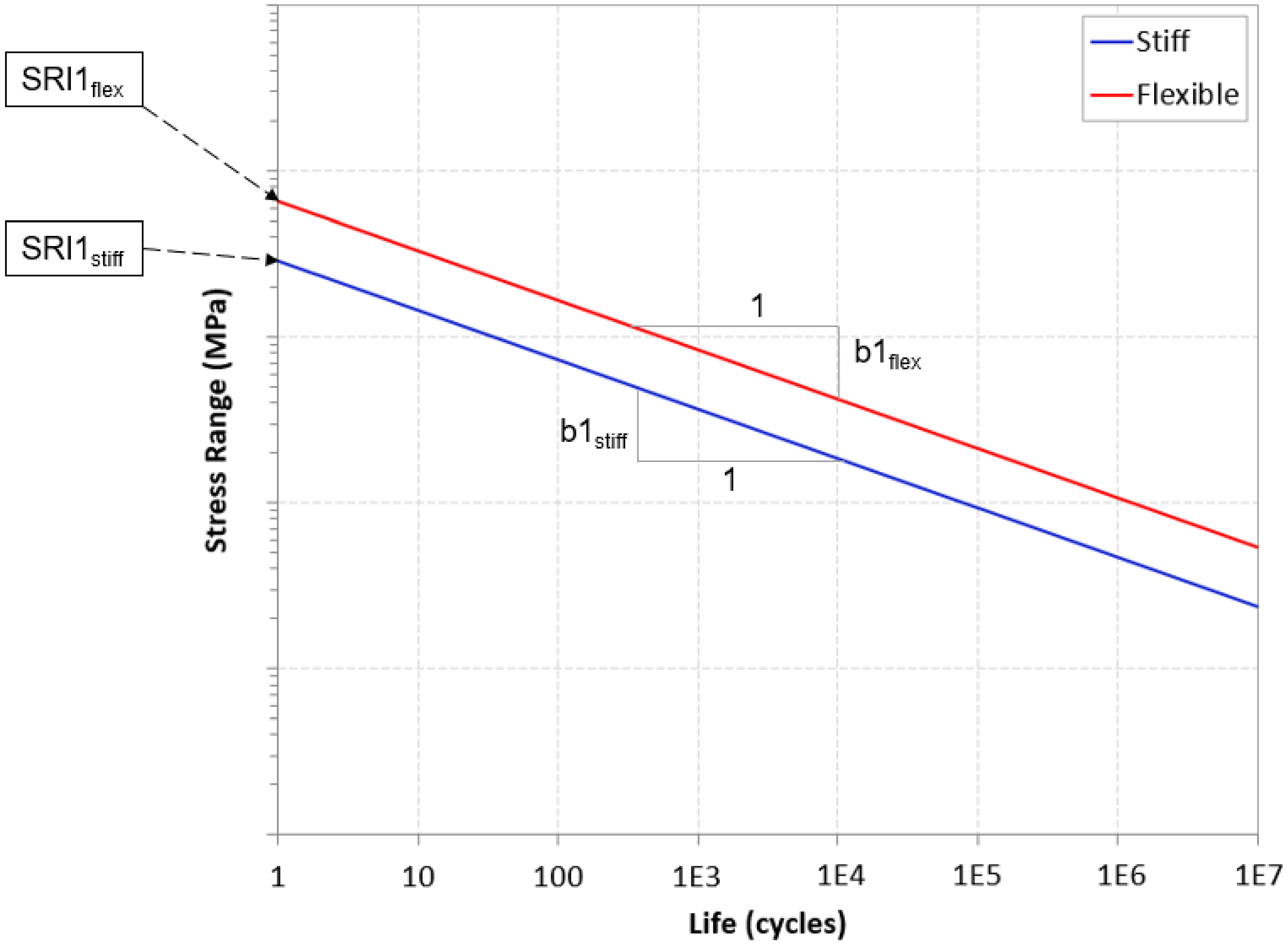
Optimisation and S-N curves generation



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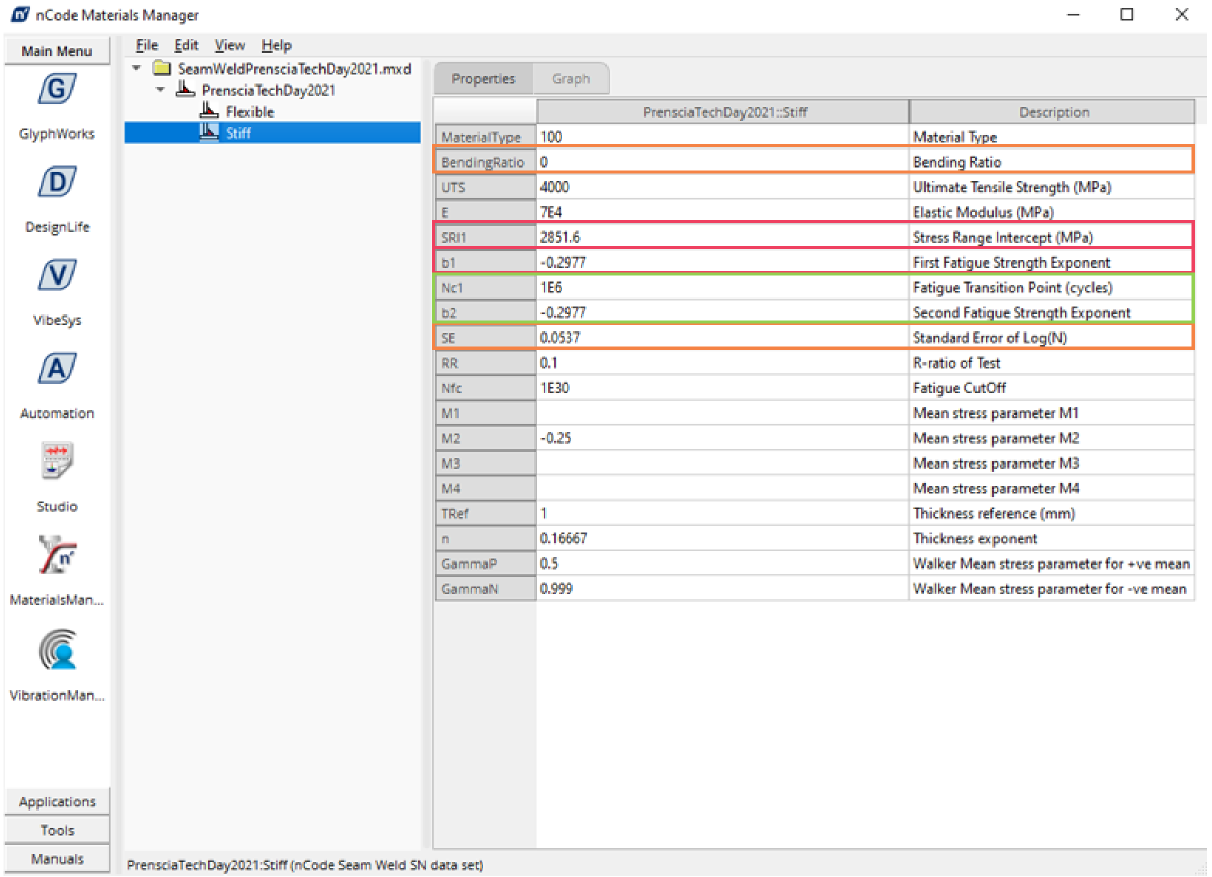
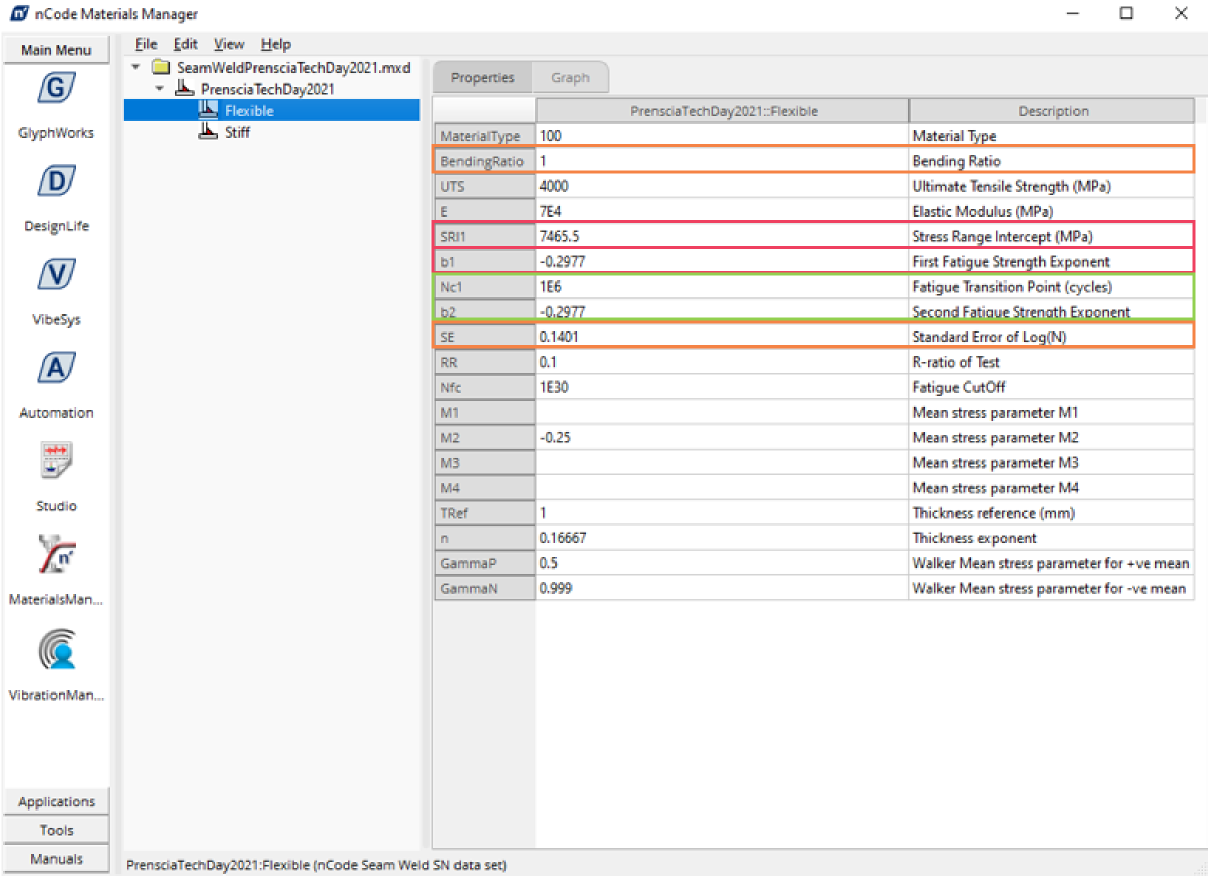
Optimisation and S-N curves generation

- Creation of material database in nCode Material Manager (idealised values)

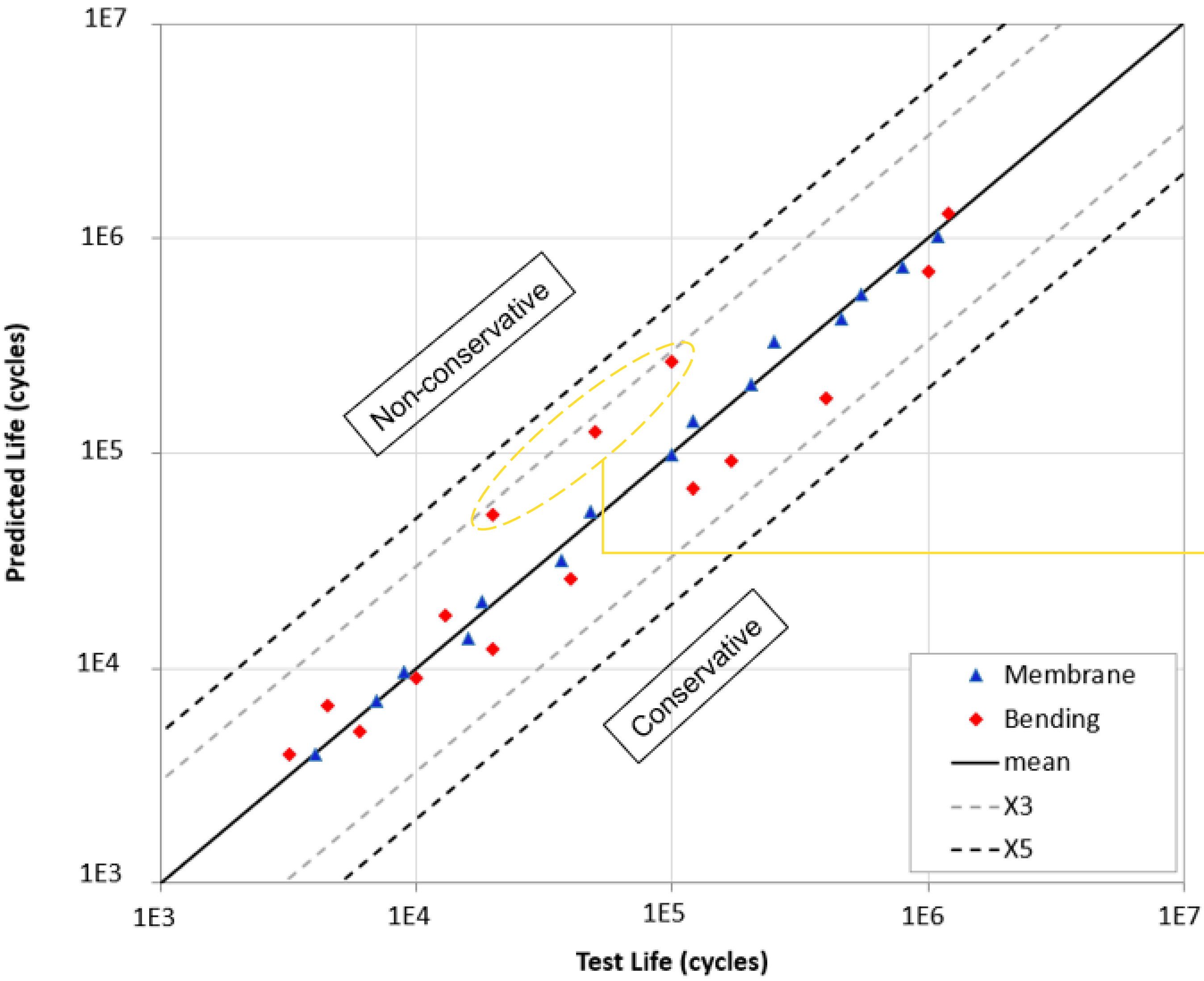


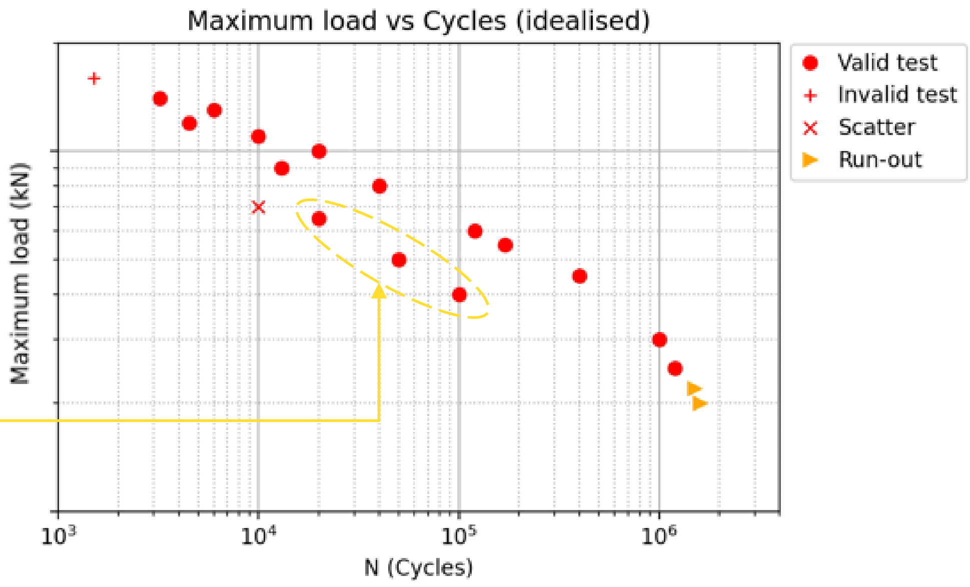
	PrensciaTechDay2021::Stiff	Description
MaterialType	100	Material Type
BendingRatio	0	Bending Ratio
UTS	4000	Ultimate Tensile Strength (MPa)
E	7E4	Elastic Modulus (MPa)
SRI1	2851.6	Stress Range Intercept (MPa)
b1	-0.2977	First Fatigue Strength Exponent
Nc1	1E6	Fatigue Transition Point (cycles)
b2	-0.2977	Second Fatigue Strength Exponent
SE	0.0537	Standard Error of Log(N)
RR	0.1	R-ratio of Test
Nfc	1E30	Fatigue CutOff
M1		Mean stress parameter M1
M2	-0.25	Mean stress parameter M2
M3		Mean stress parameter M3
M4		Mean stress parameter M4
TRef	1	Thickness reference (mm)
n	0.16667	Thickness exponent
GammaP	0.5	Walker Mean stress parameter for +ve mean
GammaN	0.999	Walker Mean stress parameter for -ve mean



	PrensciaTechDay2021::Flexible	Description
MaterialType	100	Material Type
BendingRatio	1	Bending Ratio
UTS	4000	Ultimate Tensile Strength (MPa)
E	7E4	Elastic Modulus (MPa)
SRI1	7465.5	Stress Range Intercept (MPa)
b1	-0.2977	First Fatigue Strength Exponent
Nc1	1E6	Fatigue Transition Point (cycles)
b2	-0.2977	Second Fatigue Strength Exponent
SE	0.1401	Standard Error of Log(N)
RR	0.1	R-ratio of Test
Nfc	1E30	Fatigue CutOff
M1		Mean stress parameter M1
M2	-0.25	Mean stress parameter M2
M3		Mean stress parameter M3
M4		Mean stress parameter M4
TRef	1	Thickness reference (mm)
n	0.16667	Thickness exponent
GammaP	0.5	Walker Mean stress parameter for +ve mean
GammaN	0.999	Walker Mean stress parameter for -ve mean

Optimisation and S-N curves generation – Checks





Bending

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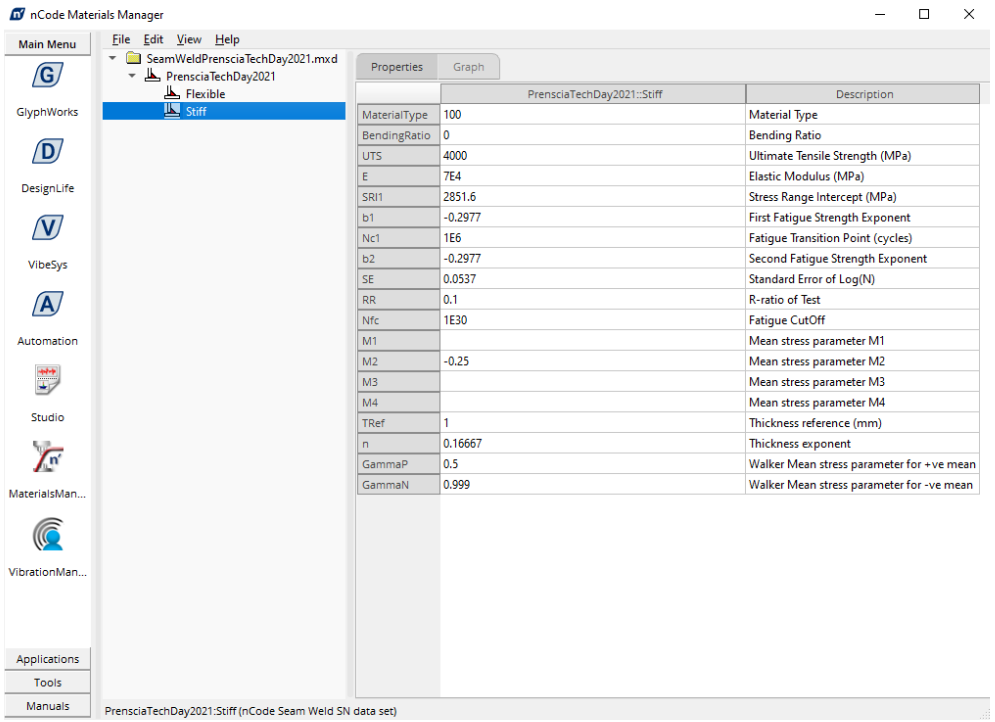
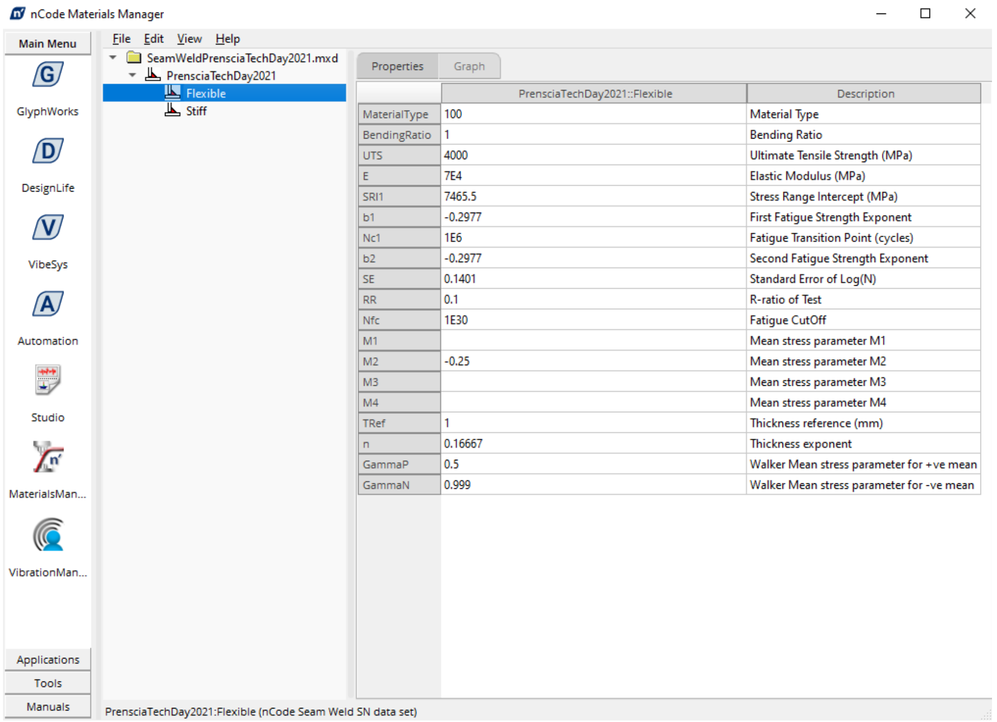
Optimisation and S-N curves generation – Checks





- Re-run nCode DesignLife analysis using the newly generated material database;
- Check that the most damaged element coincides with the one from the previous analysis and considered for the optimisation;
- Check that the new DesignLife analysis produces the same life estimates resulting from the previous optimisation.

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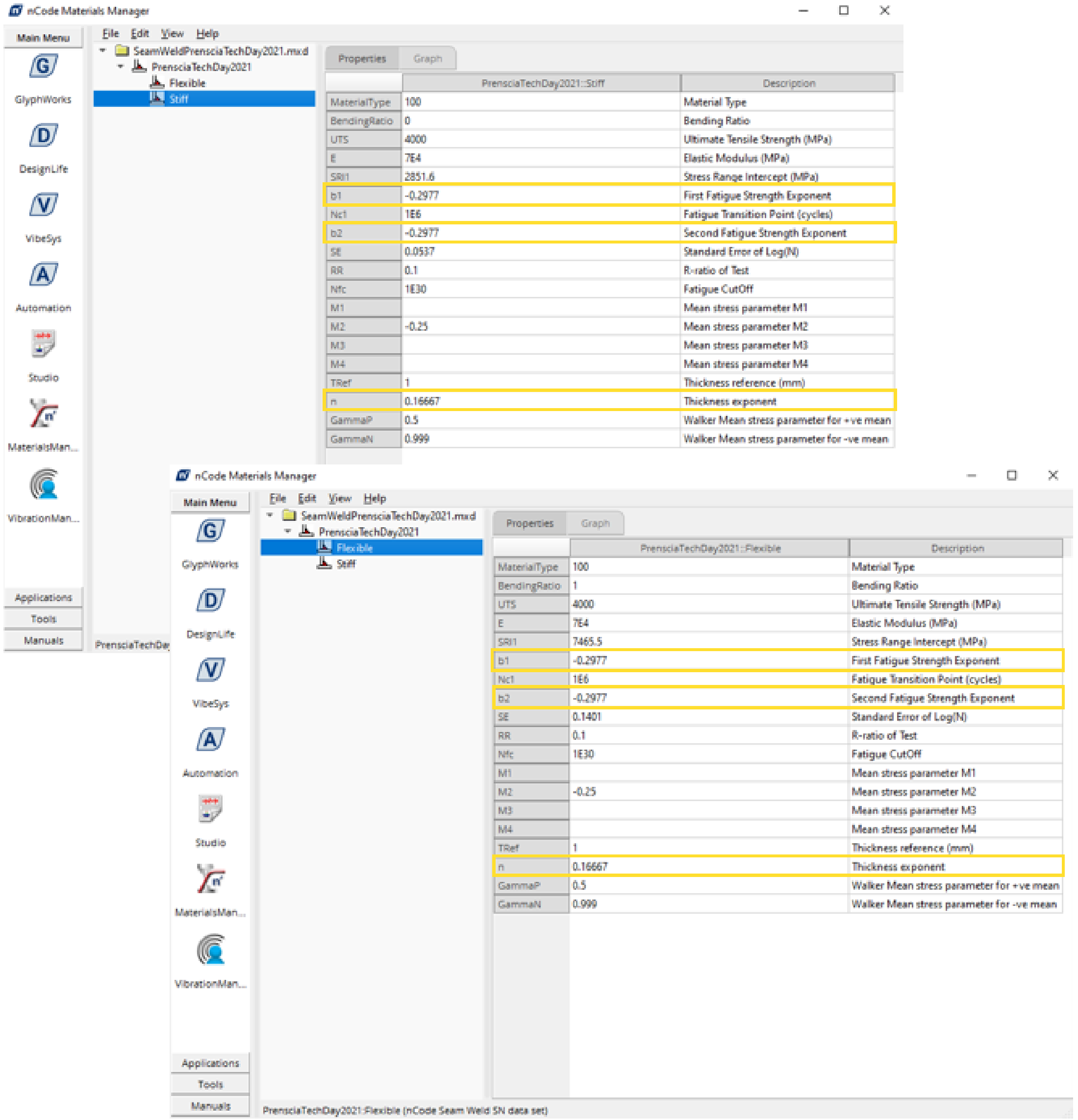
Optimisation and S-N curves generation – Further considerations

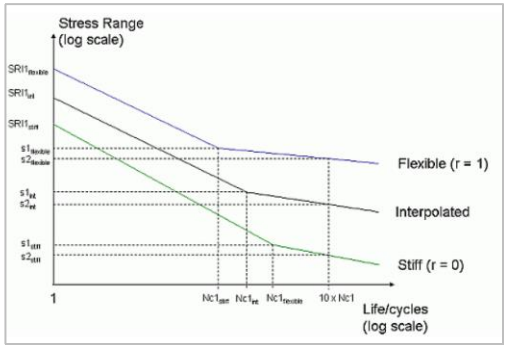
- Other parameters can potentially be varied and optimised:
  - First fatigue strength exponents, $b1_{stiff}$ and $b1_{flex}$, can be varied independently.
  - Thickness correction exponent, n

$$c_t = \left(\frac{T_{ref}}{t}\right)^n$$

    Several thicknesses for both membrane and bending specimens must be tested.

  - Second fatigue strength exponents, $b2_{stiff}$ and $b2_{flex}$ (similarly to $b1_{stiff}$ and $b1_{flex}$, they can be kept equal or be varied independently).





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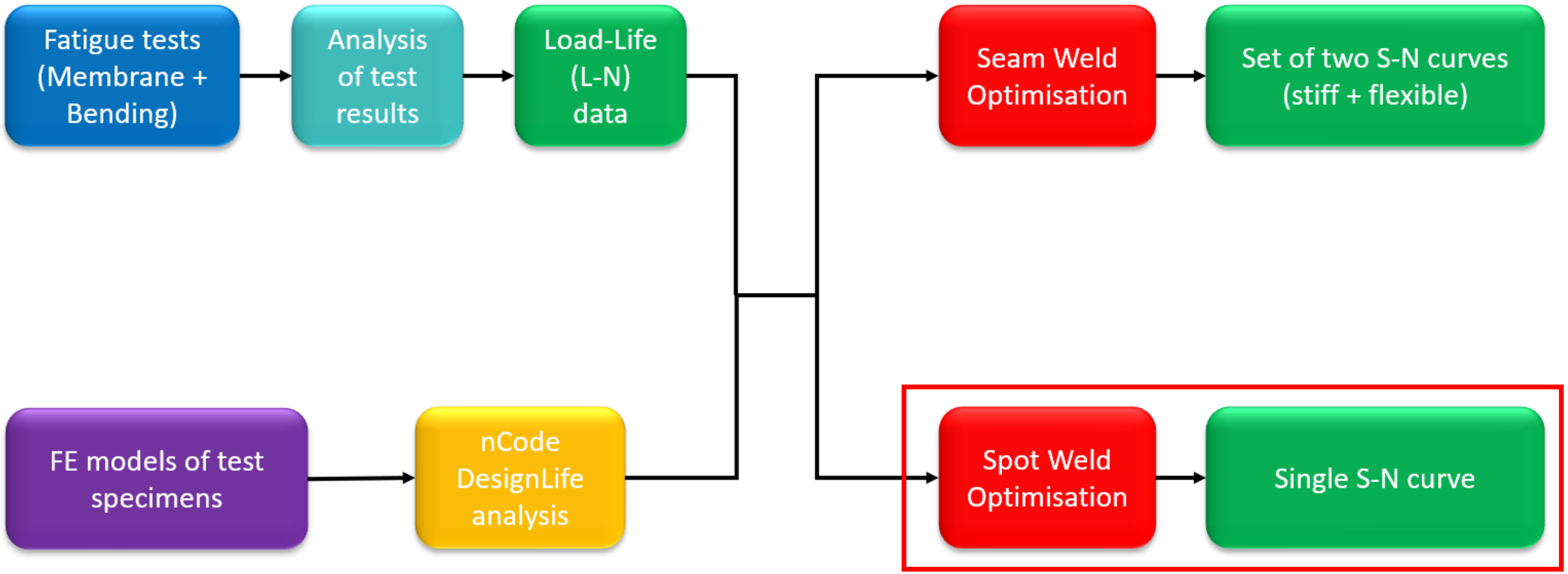
Optimisation and S-N curve generation
– Spot Welds –



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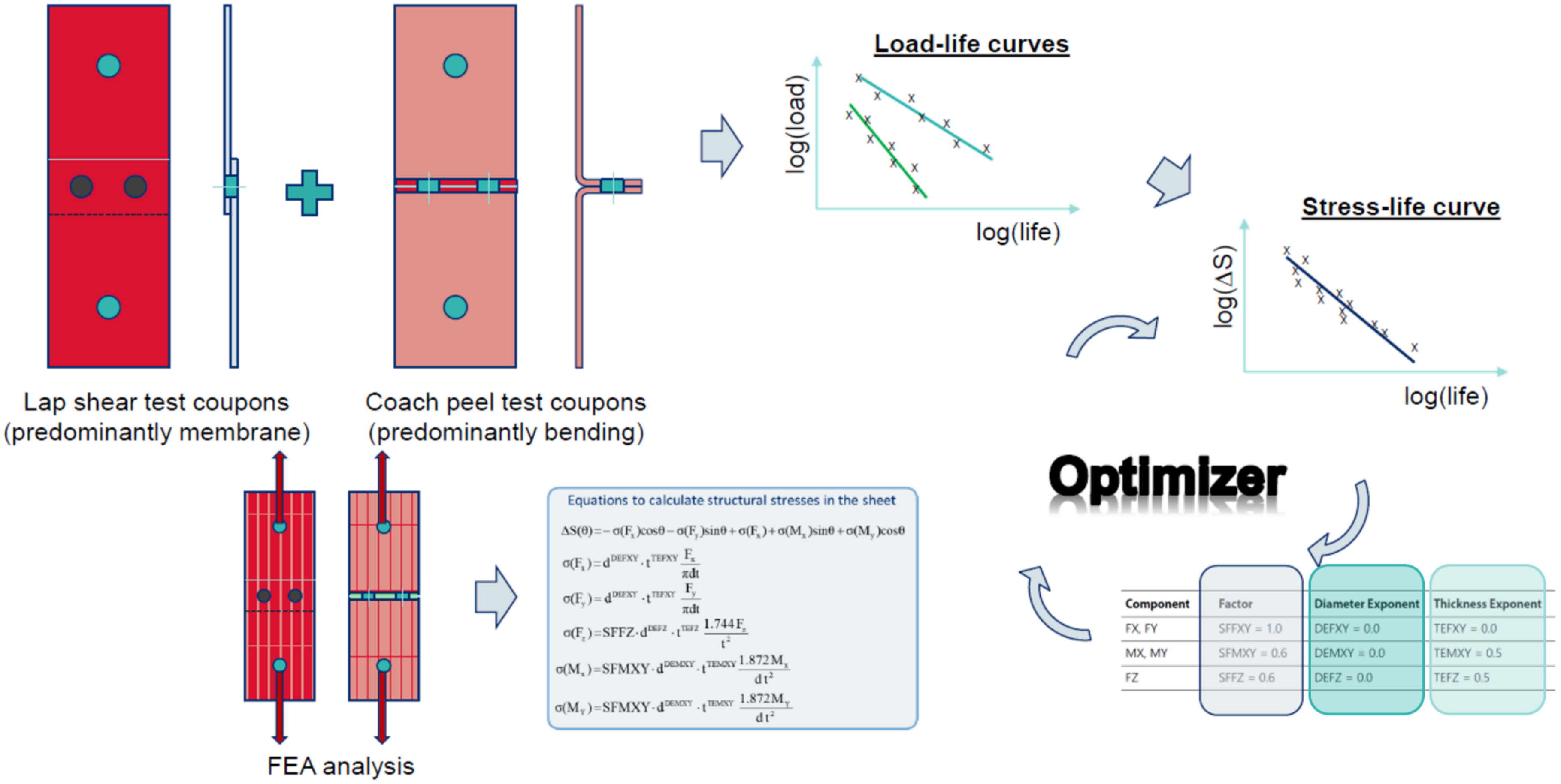
Optimisation and S-N curve generation



- A material database can be created in nCode Material Manager
- The same checks performed for the Seam Weld optimization and S-N curves generation applies

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Thank You

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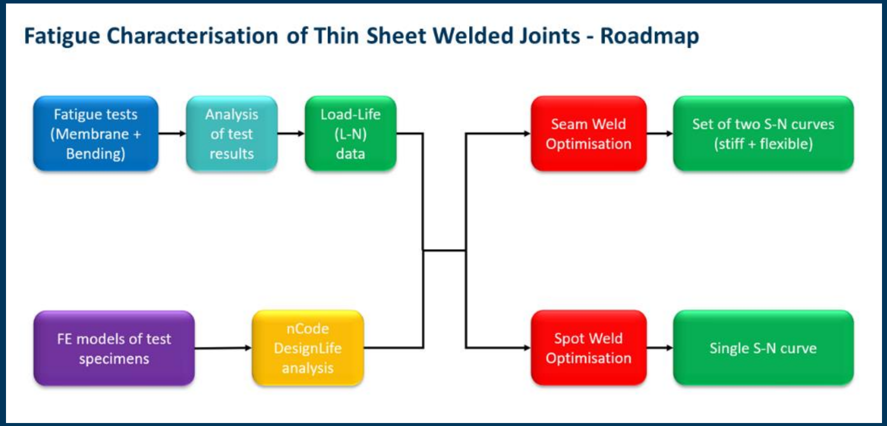

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