Virtual Seminar Series – Tuesday 2, 9, 16 November

Fatigue Simulations of Welded Joints at NIO

Presented by Mr Artur Tarasek
Durability CAE
NIO

Tuesday, November 2, 2021

Fatigue Simulations of Welded Joints at NIO

Abstract

NIO's mission is to shape a joyful lifestyle by offering smart, premium electric vehicles and providing the best user experience through technological innovation, smart design and freedom of worry-free journeys. NIO was founded in November 2014 as a global electric vehicle company, with world-class research and development, design and manufacturing centres in China, United States, Germany and the UK.

NIO, as a start-up company, has a unique opportunity to re-think what the user’s experience of owning an electric vehicle should feel like which is reflected in the product design and engineering. Nevertheless, being a relatively new company, creates some challenges as NIO might not have a luxury of having legacy data and processes that more established OEM’s possess which was the motivation for the CAE capability enhancement discussed here.

Modern, light weight vehicle manufacturers require a wide range of joining technologies to provide a mass-efficient and cost-efficient product that withstands the variable loading that the structure is exposed to during the life of the vehicle. Given the ease and speed with which the resistance spot welding process can be automated, it is a primary joining process in high volume steel vehicle manufacturing.

Due to a complex loading that the joint might be exposed to it is important to understand the failure modes that might occur during the extensive vehicle testing and develop a suitable durability prediction technique to avoid costly, late design changes.

A significant amount of joining configurations in the modern vehicle’s car body requires an approach that will provide good quality data with reduced scope of testing. Good practices and challenges associated with creating a resistance spot weld’s durability prediction methodology will be discussed.

About the presenter, Mr Artur Tarasek, Durability CAE, NIO

Artur Tarasek completed his Masters’ in Mechanical Engineering at the AGH University of Science and Technology in Cracow, with a focus on numerical methods in mechanical design. His career started in 2014 in the German railway industry, followed by relocation to the UK and 3 years of body and closure development for Jaguar Land Rover. After joining NIO in 2017 as a Staff Engineer, Artur focussed on NVH and durability development of body structures. More recently he has expanded NIO’s capability for fatigue simulation methods, with a focus on spot welded joints.

HOTTINGER BRÜEL & KJÆR

Fatigue Simulations of Welded Joints at NIO

02/11/2021

Content

1.0

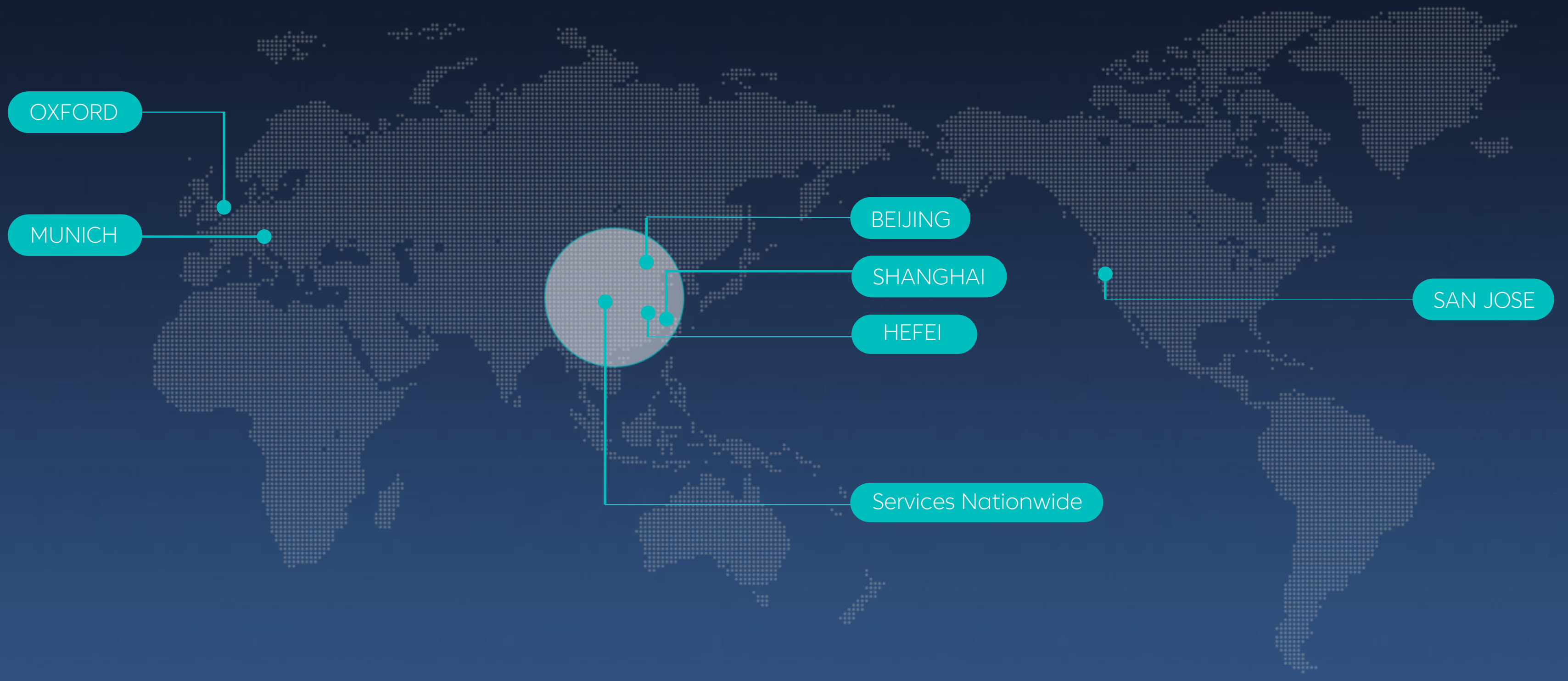
INTRODUCTION

NIO is more than a car company

Conceived and planned since 2012 and formally founded on November 25, 2014. NIO is a global company that designs, develops, and produces smart, high-performance, premium electric vehicles. Our aspiration is to shape a joyful lifestyle for our users through thoughtful design, amazing services, and cutting-edge technology.

Fatigue Simulations of Welded Joints at NIO

NIO has established R&D centers and manufacturing facilities in Shanghai, Hefei, Beijing, Oxford, San Jose, Munich and other places, and built up an initial user service system with nationwide coverage in China.



NIO es8

FLAGSHIP SMART ELECTRIC SUV

NIO es6

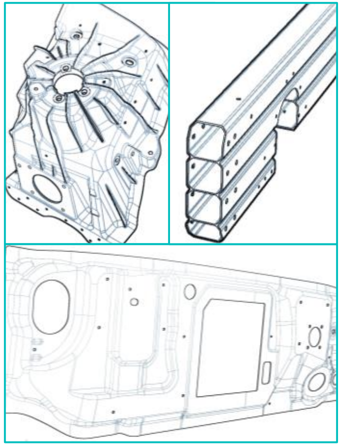
SMART ELECTRIC ALL-AROUND SUV


NIO ec6
SMART ELECTRIC COUPE SUV
ec6


NIO eT7
READY FOR TOMORROW

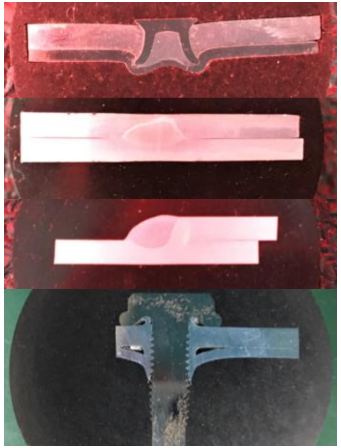
Complexity
Modern lightweight body structure

Material technologies



Variety of material types and component manufacturing technologies enables truly lightweight architecture by choosing the right material for the right location.

Joining technologies

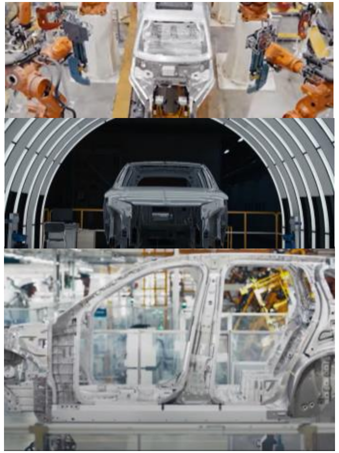


Different joining technologies are required to robustly join hundreds of body components.

Loading conditions

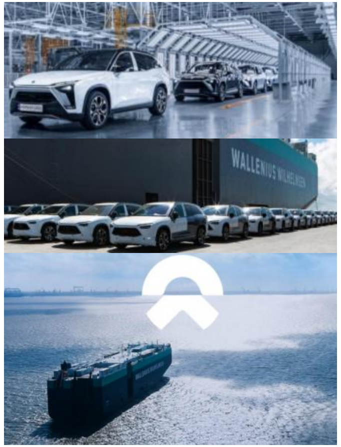
The structure will be exposed to, and needs to withstand a wide range of loading conditions.

Manufacturing



Structural design executed in a way that allows for efficient manufacturing processes.

Mass production



Architecture design that enables scalability.

Developing a failure prediction methodology
Important factors to consider

NIO's extremely ambitious lead time to market requires **accurate virtual failure prediction capabilities**.

Establishing these is crucial for avoiding issues during the vehicle's physical testing & users operation, which helps to eliminate:

- changes to component's due to late design modifications,
- costs associated with modifications to already established manufacturing processes,
- delaying product launch,
- reduction in user's experience.

2.0

TESTING & DATA HANDLING

2.1

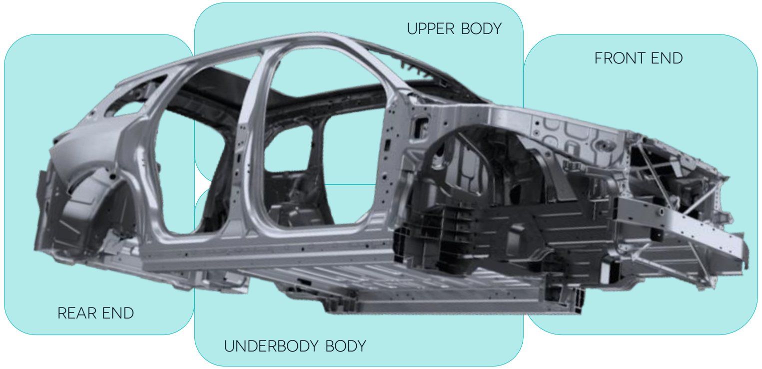
TESTING & DATA HANDLING

Defining a test matrix

Defining the test matrix
Quantitative approach and risk assessment

One of the factors that should contribute to selecting the testing priorities is a **durability risk assessment** of the structure.

It is also important to understand the **wide range of joint types** across the body structure

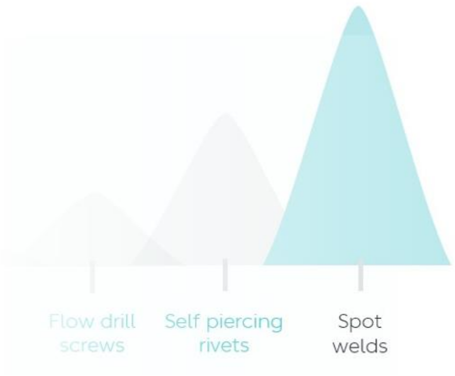


Developments in material science have allowed for high strength materials to be commonly used, which enables **low thickness structural components**.
The increase in stress applied to a car body due to a reduction in material thickness causes the fatigue strength of the structure to decline. With resistance spot weld's fatigue performance being virtually **independent from base material strength**, makes this joint especially vulnerable to fatigue failures.

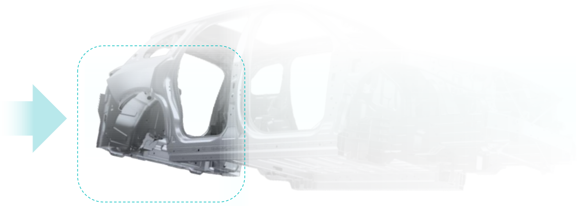
Defining the test matrix

Material selection

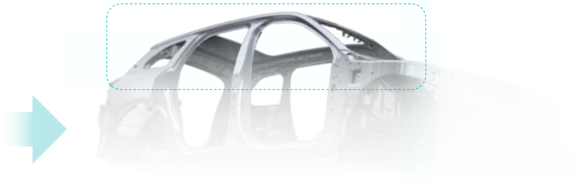
Understanding the distribution of thickness combinations across different body materials



Thickness Combination [mm]	Material 1	Material 2	Amount
1.5 – 1.5	DP Steel	DP Steel	40%
	DP Steel	HSS	30%
	HSS	HSS	20%
	DP Steel	CR Steel	10%



Thickness Combination [mm]	Material 1	Material 2	Amount
0.8 – 0.8	CR Steel	CR Steel	60%
	HSS	CR Steel	40%



2.2

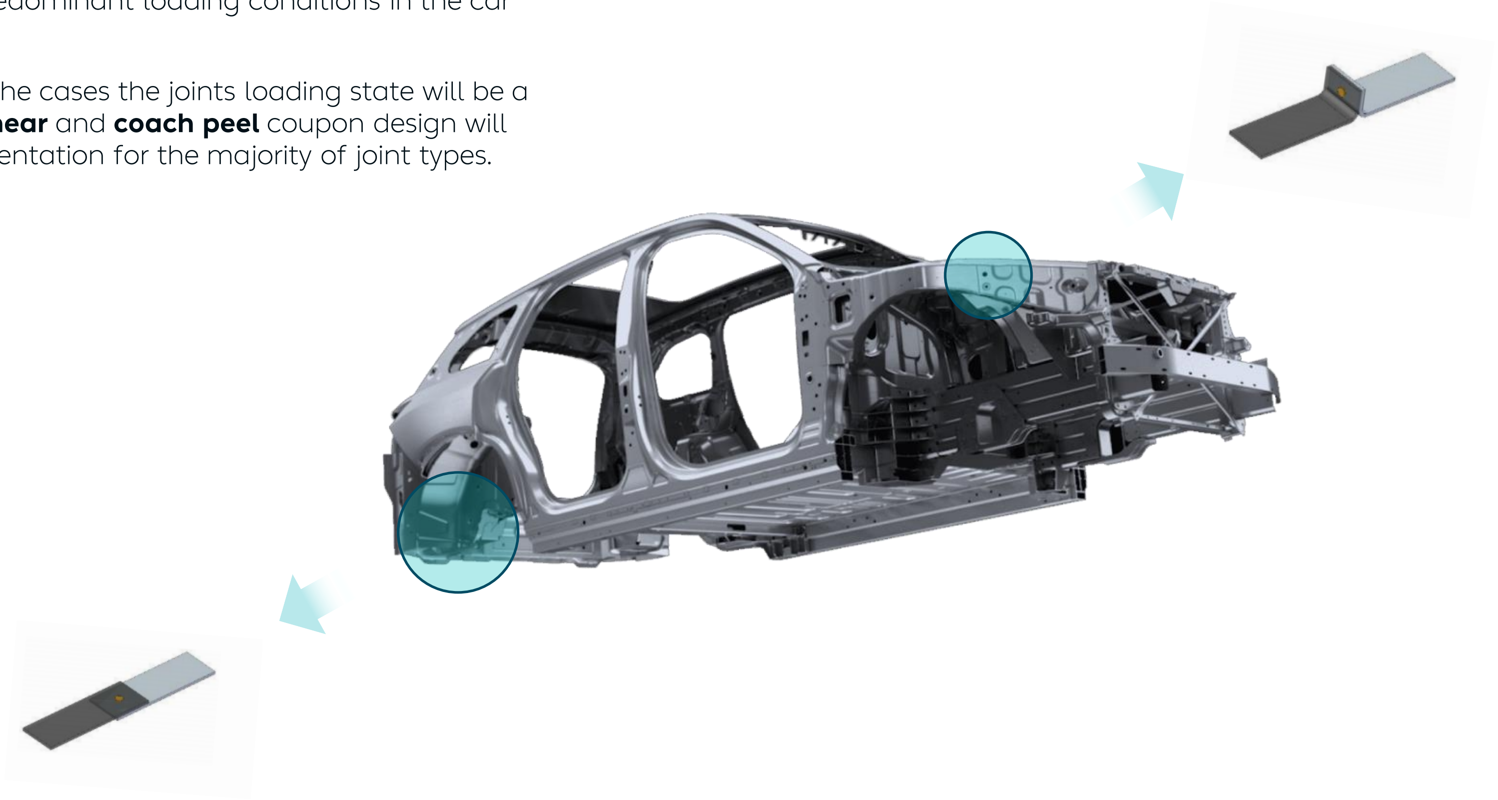
TESTING & DATA HANDLING

Test specimen

Test specimen
Loading condition

Understanding the predominant loading conditions in the car body structure.

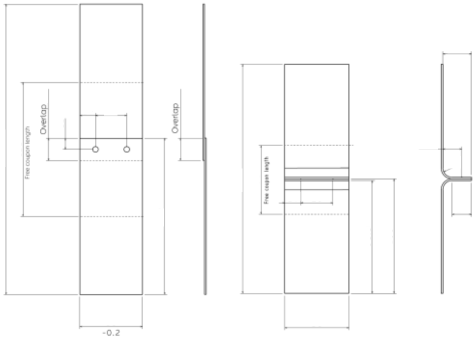
Although, in most of the cases the joints loading state will be a complex one, a **lap shear** and **coach peel** coupon design will provide a good representation for the majority of joint types.

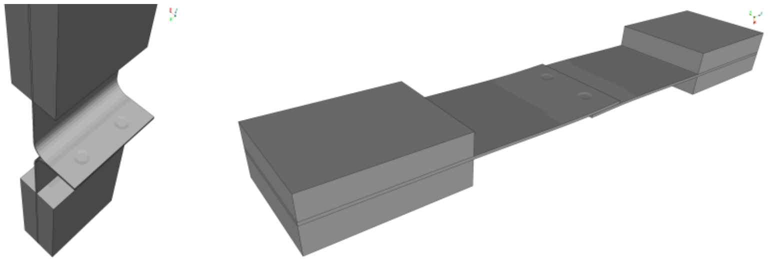


Test specimen
Design

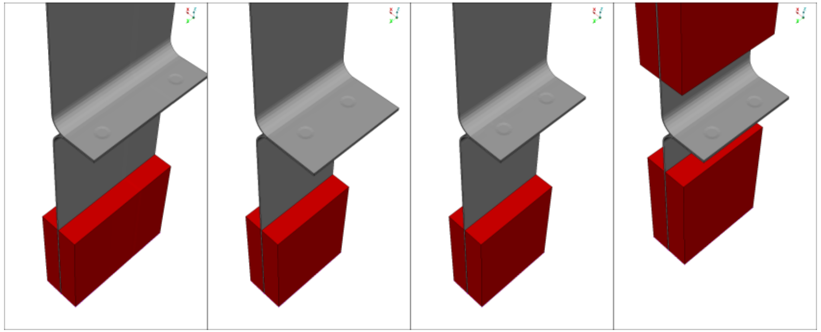
Specimens must be representative of the condition on the production vehicle, therefore company's internal design criteria must be satisfied with regards to:

- Minimum nugget size
- Minimum flange overlap
- RSW's center to the panels edge distance
- RSW's center to the panels wall distance (for coach peel)
- Minimum radius for coach peel specimens
- Spacing between the joints





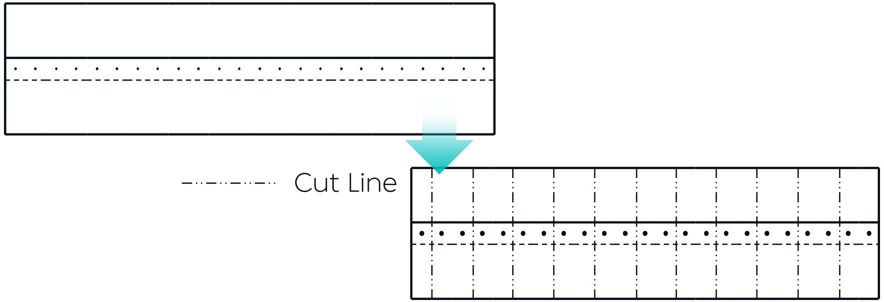
The behavior of the specimen can be better understood with a high fidelity coupon model using a fully non-linear CAE analysis.



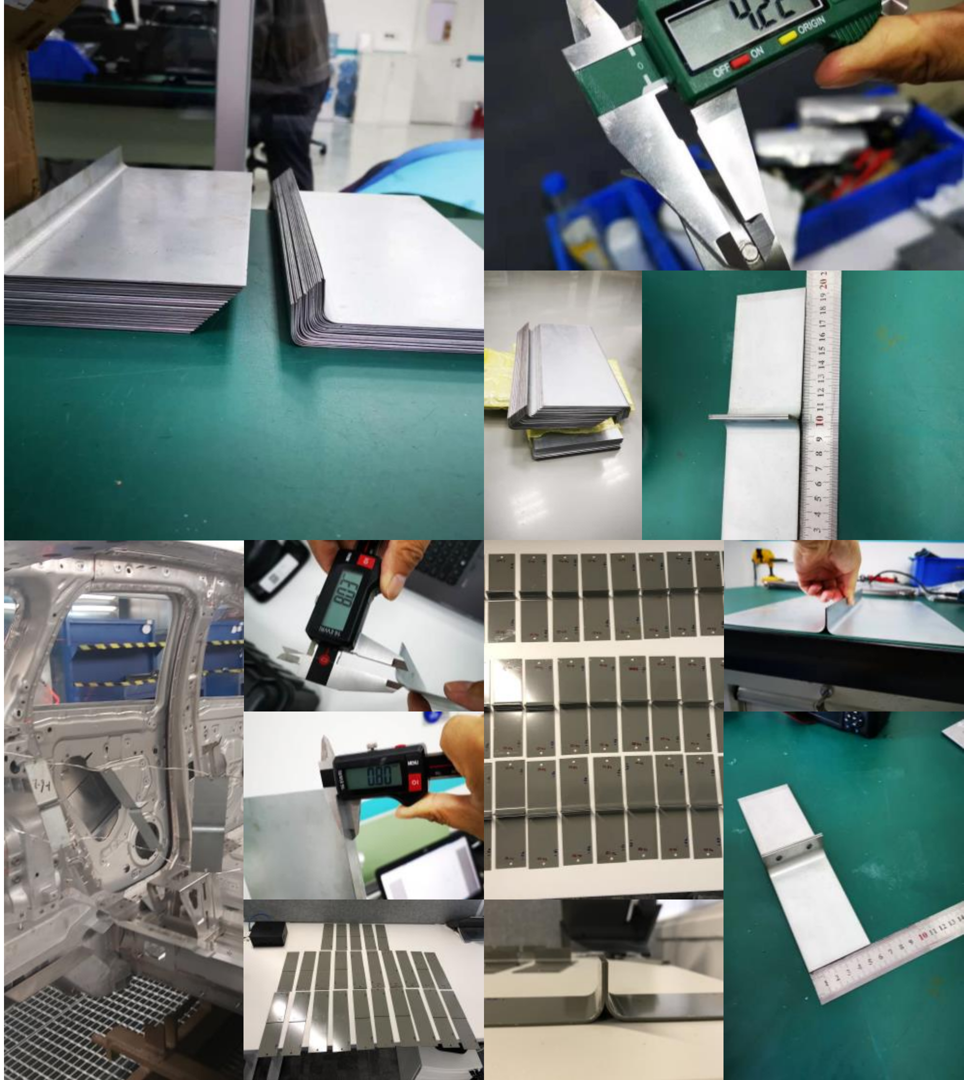
Sensitivity studies performed to understand the influence of different design parameters

Test specimen
Manufacturing

Material blanks; welding and cutting the specimens into the final shape.



Special care should be taken while cutting the specimens out of the blank – edge quality is important for valid test results – water jet cut / laser cut as a preference



2.3

TESTING & DATA HANDLING

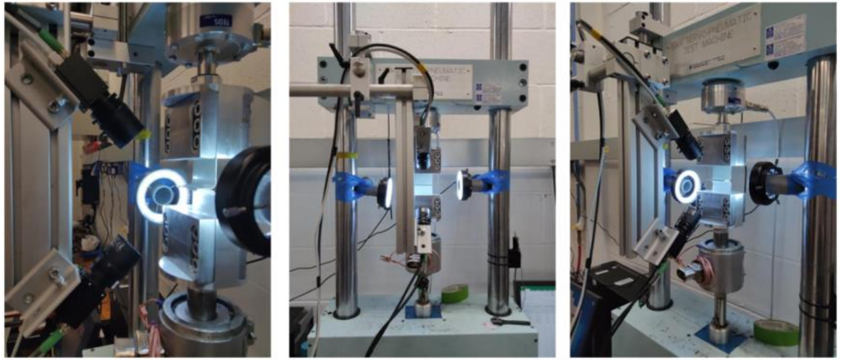
Failure definition

TESTING & DATA HANDLING

Failure criteria

Different failure criteria might be formulated depending on the preference.

The fatigue analysis can be performed by considering the number of cycles corresponding to the **first visible crack.**



HBK Prenscia test rig

2.4

TESTING & DATA HANDLING

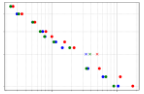
Damage model formulation

Formulating the SN curve
Process overview

We are here

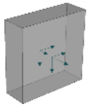
Step 1

Load vs Life



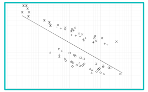
Step 2

External load to Internal load



Step 3

Radial stress calculation



Step 4

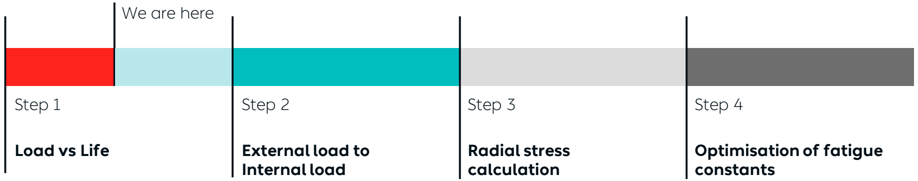
Optimisation of fatigue constants

Formulating the SN curve

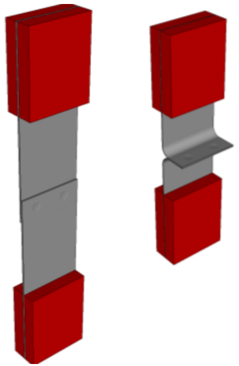
Load vs Life

Fatigue damage model consists of:

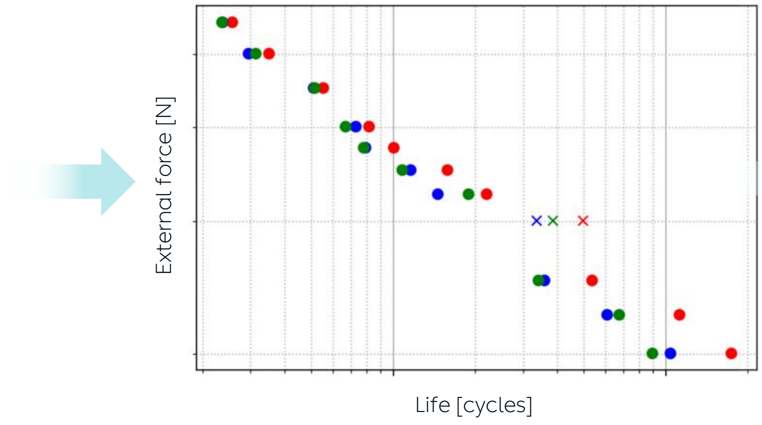
- stress-life curve,
- specific joint modelling technique,
- nugget diameter statistical model



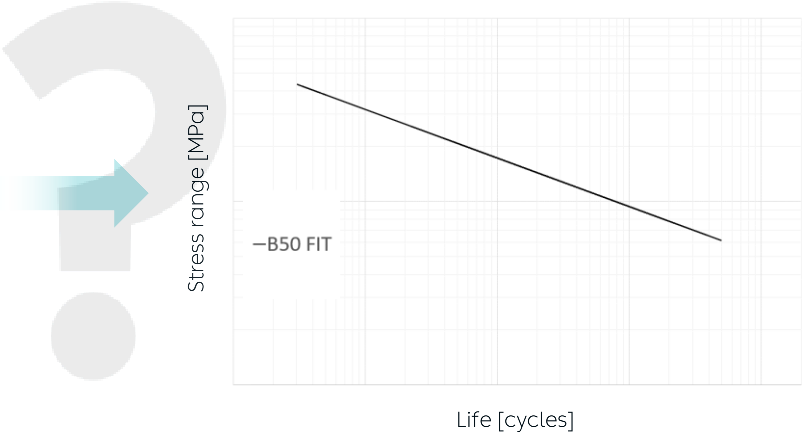
Coupon level testing



External force applied to the specimen vs Test Life



CAE Stress vs Test Life

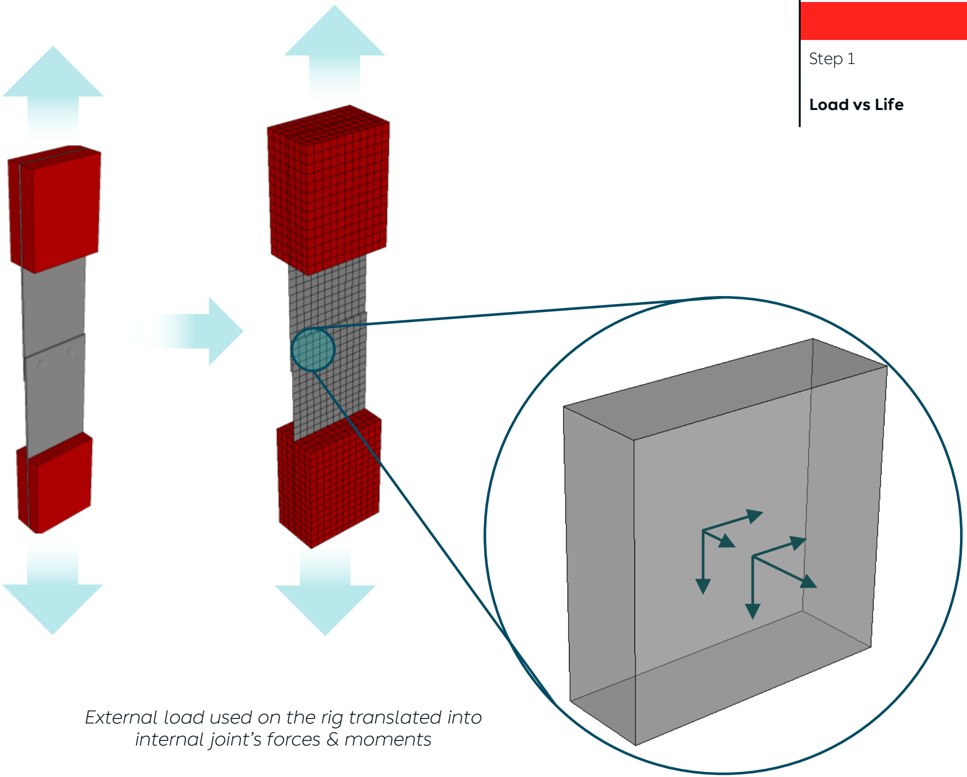


Formulating the SN curve

External load to internal load

We are here

Step 1	Step 2	Step 3	Step 4
Load vs Life	**External load to Internal load**	**Radial stress calculation**	**Optimisation of fatigue constants**



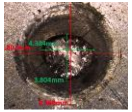
External load used on the rig translated into internal joint's forces & moments

Thickness Combination [mm]	Fx	Fy	Fz	Mx	My	Mz
1.5 – 1.5						
LAP SHEAR	[N]	[N]	[N]	[Nmm]	[Nmm]	[Nmm]
COACH PEEL	[N]	[N]	[N]	[Nmm]	[Nmm]	[Nmm]
0.8 – 0.8						
LAP SHEAR	[N]	[N]	[N]	[Nmm]	[Nmm]	[Nmm]
COACH PEEL	[N]	[N]	[N]	[Nmm]	[Nmm]	[Nmm]

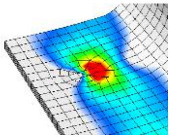
Fatigue performance prediction
Nugget diameter statistical model

nCode DesignLife allows for defining the **nugget diameter as a function of the connected panel thicknesses**.

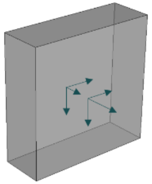
This is crucial for an accurate radial stress calculation, therefore a range of possible diameters has to be understood using vehicle teardown data.



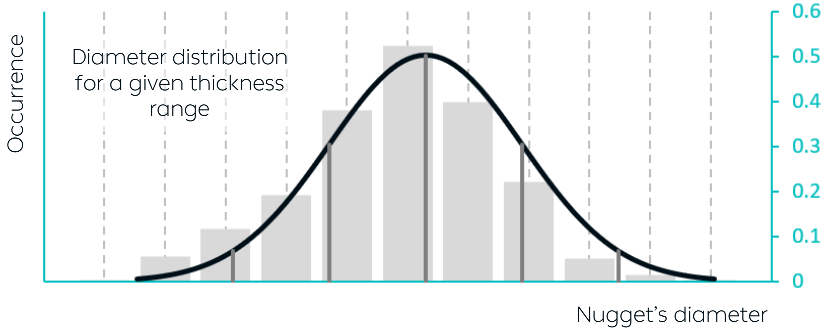
Nugget's diameter

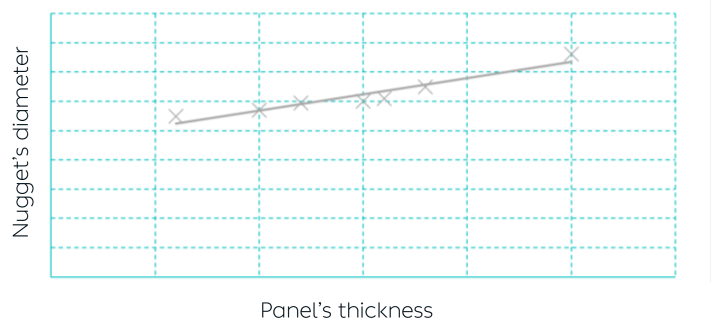


Radial stress



Internal joint forces and moments

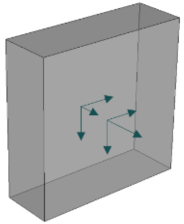




Formulating the SN curve

Radial stress calculation

In order to obtain a **stress range** necessary to formulate an SN curve, the radial stress around the joint needs to be calculated. This can be done with the use of Rupp's equations.



Joint's internal loads

$$\sigma_{sheet1} = -\sigma_{\max}(FX1)\cos\theta - \sigma_{\max}(FY1)\sin\theta + \sigma(FZ1) + \sigma_{\max}(MX1)\sin\theta - \sigma_{\max}(MY1)\cos\theta$$

...where:

$$\sigma_{\max}(FX1) = \frac{FX1}{\pi d s_1} \times SFFXY \times d^{DEFXY} \times s_1^{TEFXY}$$

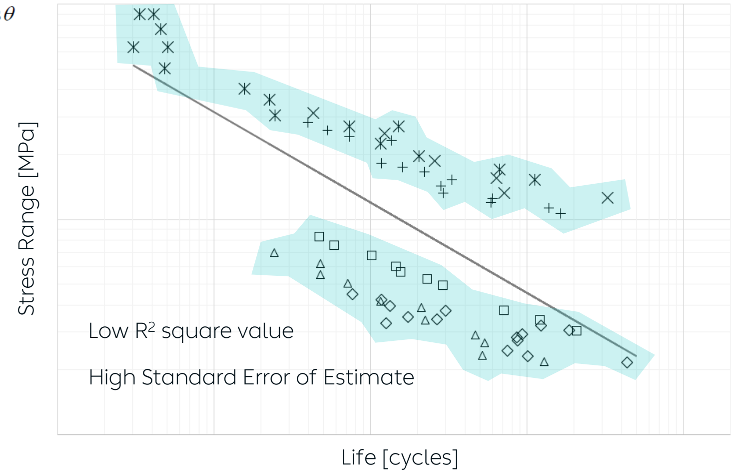
$$\sigma_{\max}(FY1) = \frac{FY1}{\pi d s_1} \times SFFXY \times d^{DEFXY} \times s_1^{TEFXY}$$

$$\sigma(FZ1) = \frac{1.744 \cdot FZ1}{s_1^2} \times SFFZ \times d^{DEFZ} \times s_1^{TEFZ}$$

$$\sigma_{\max}(MX1) = \frac{1.872 \cdot MX1}{d s_1^2} \times SFMXY \times d^{DEMXY} \times s_1^{TEMXY}$$

$$\sigma_{\max}(MY1) = \frac{1.872 \cdot MY1}{d s_1^2} \times SFMXY \times d^{DEMXY} \times s_1^{TEMXY}$$

nCode DesignLife Theory: Analysis Run



Data points & SN curve for unoptimized fatigue constants

Formulating the SN curve

Optimisation of fatigue constants

We are here

- Step 1 — **Load vs Life**
- Step 2 — **External load to Internal load**
- Step 3 — **Radial stress calculation**
- Step 4 — **Optimisation of fatigue constants**

$$\sigma_{sheet1} = -\sigma_{\max}(FX1)\cos\theta - \sigma_{\max}(FY1)\sin\theta + \sigma(FZ1) + \sigma_{\max}(MX1)\sin\theta - \sigma_{\max}(MY1)\cos\theta$$

...where:

$$\sigma_{\max}(FX1) = \frac{FX1}{\pi d s_1} \times SFFXY \times d^{DEFXY} \times s_1^{TEFXY}$$

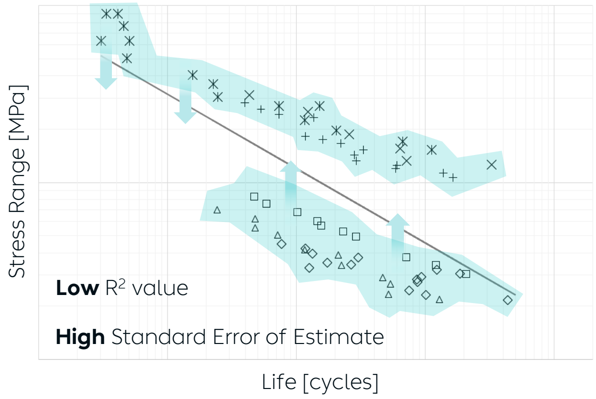
$$\sigma_{\max}(FY1) = \frac{FY1}{\pi d s_1} \times SFFXY \times d^{DEFXY} \times s_1^{TEFXY}$$

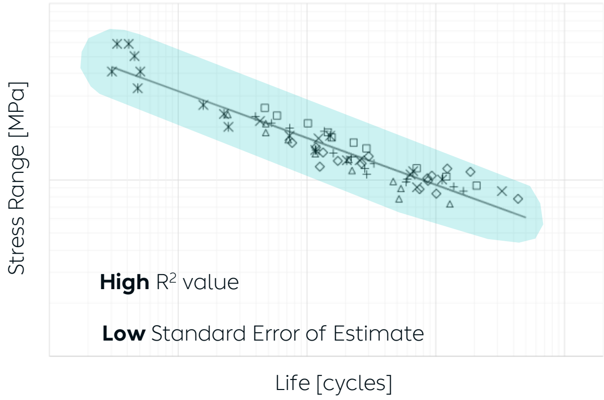
$$\sigma(FZ1) = \frac{1.744 \cdot FZ1}{s_1^2} \times SFFZ \times d^{DEFZ} \times s_1^{TEFZ}$$

$$\sigma_{\max}(MX1) = \frac{1.872 \cdot MX1}{d s_1^2} \times SFMXY \times d^{DEMXY} \times s_1^{TEMXY}$$

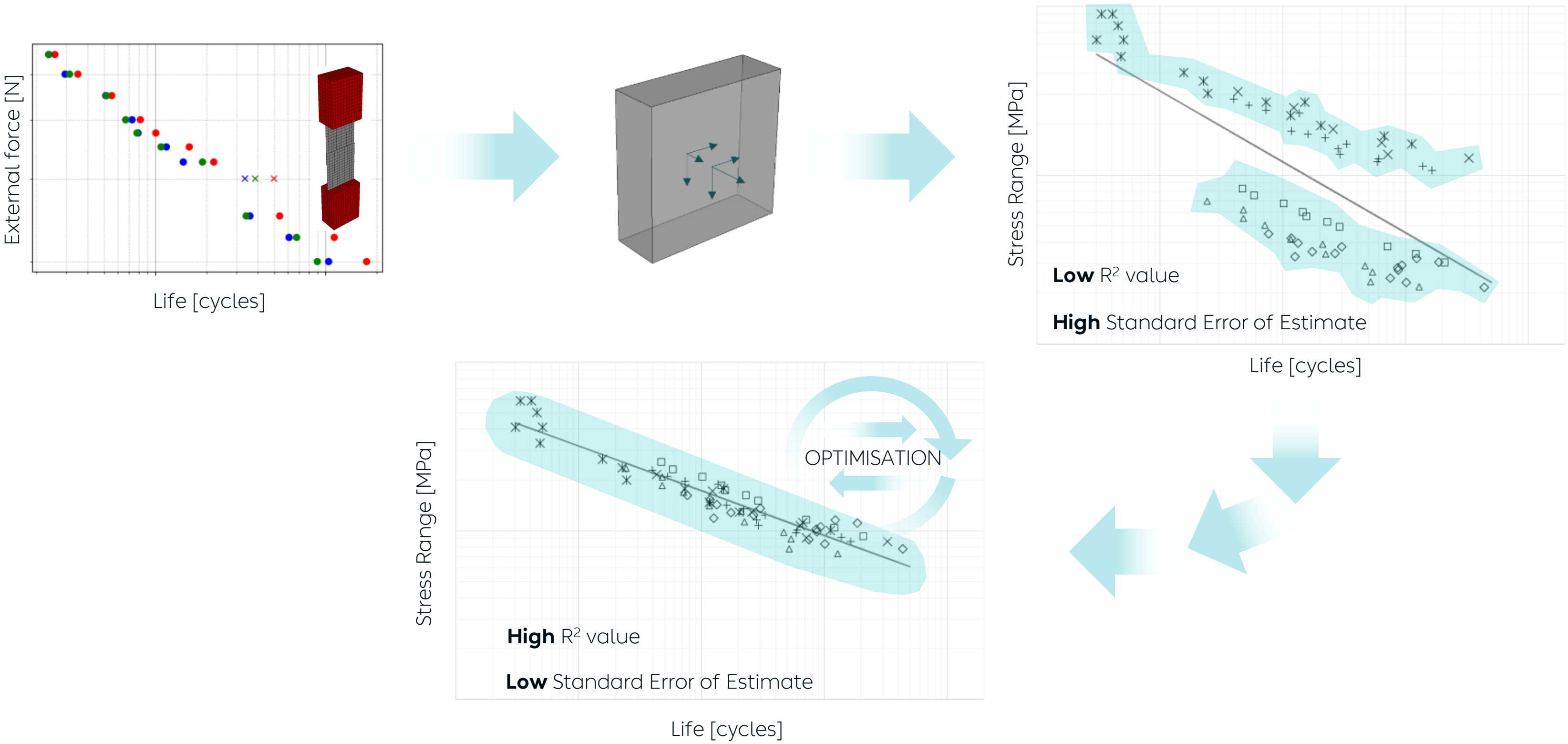
$$\sigma_{\max}(MY1) = \frac{1.872 \cdot MY1}{d s_1^2} \times SFMXY \times d^{DEMXY} \times s_1^{TEMXY}$$

The objective of the optimisation process is to **tune fatigue parameters** in a way that allows for several data families to **merge into one** that can be represented with a single curve for the **lowest scatter possible**.





Formulating the SN curve
Summary



3.0

Fatigue performance prediction

3.1

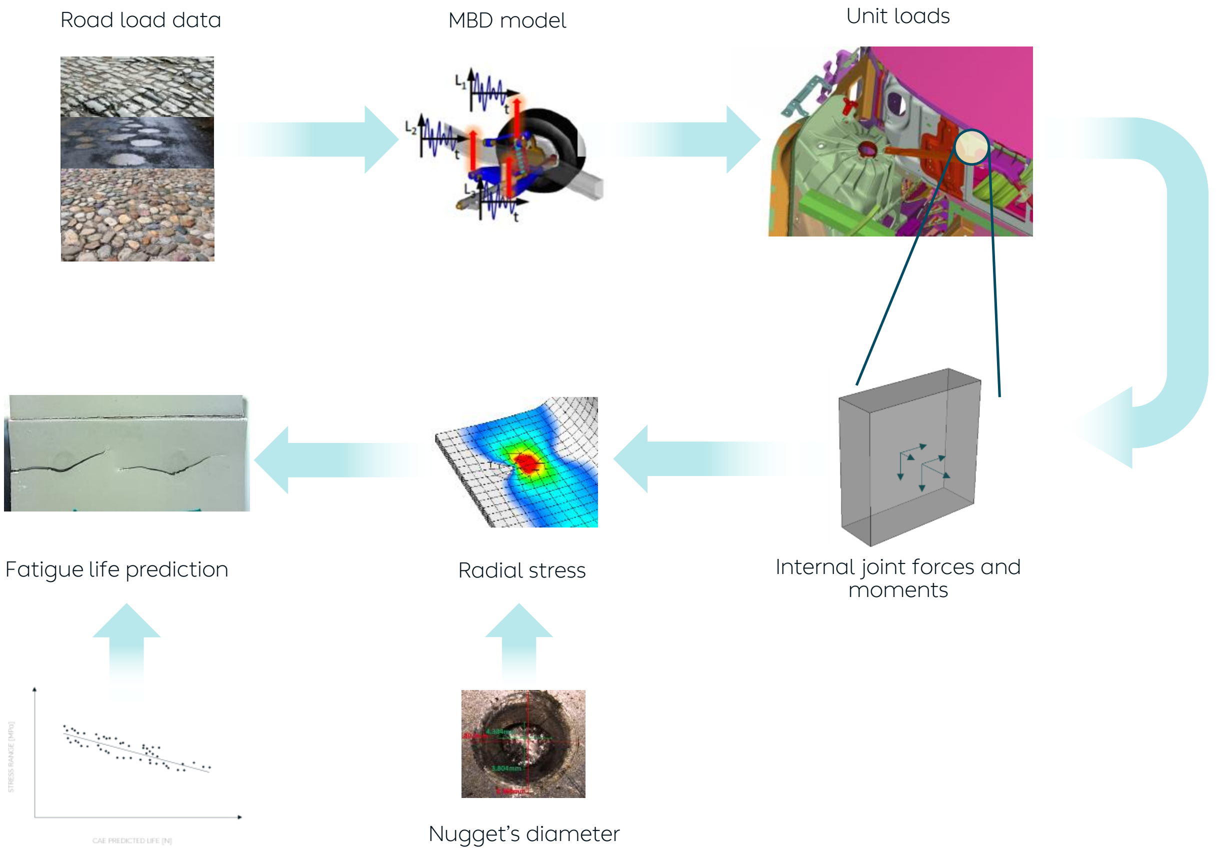
Fatigue performance prediction

Workflow

Fatigue performance prediction

Workflow

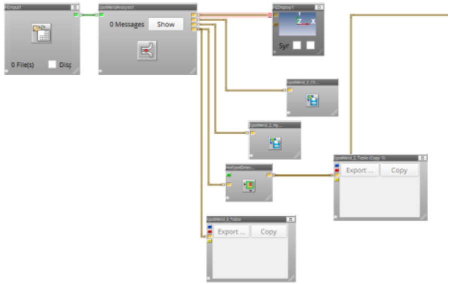
Load time histories at vehicle hardpoints are generated with multi-body models run over a virtual representation of proving ground road surfaces. Finite element body model displacements & stresses, obtained for unit loading are scaled with generated time signals. This allows for extracting **internal joint's forces and moments** which are used for calculating a time history of radial stress around the spot welded joint. Fatigue life prediction can be made with the use of rainflow analysis and a **fatigue damage model.**



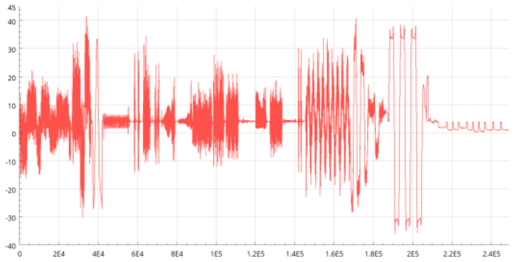
Fatigue performance prediction
Workflow

nCode DesignLife is NIO's primary tool for assessing the fatigue performance of spot welded joints.

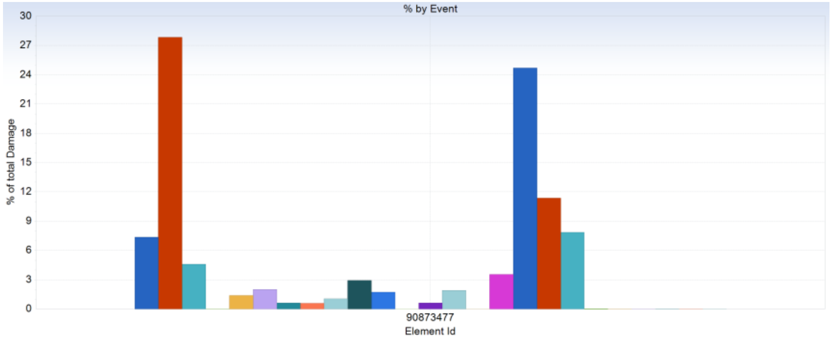
A **detailed** insight into the joint's performance can be obtained with a fairly **simple** DesignLife flow.



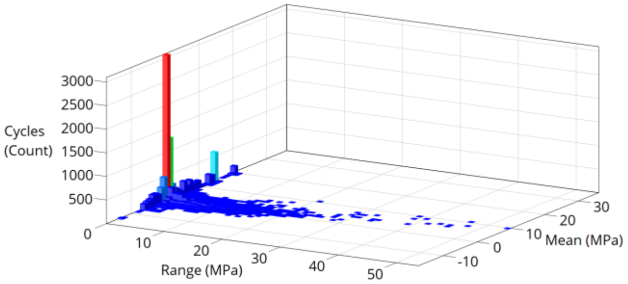
Simple nCode DesignLife flow for spot weld fatigue analysis



Stress range history for a specific spot weld



Duty cycle events contribution to the overall damage



Rainflow histogram

3.2

Fatigue performance prediction

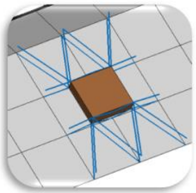
Modelling

Fatigue performance prediction
Modelling

A variety of different modelling techniques exist and are commonly used for different purposes.

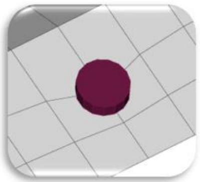
Each approach has its **pros and cons** and the selection of the appropriate technique depends on the specific application.

ACM2



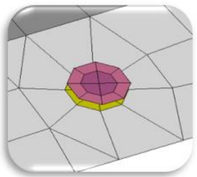
Mesh independent

1D SPOT



Mesh dependent

1D SPOT with SHELL HEAD



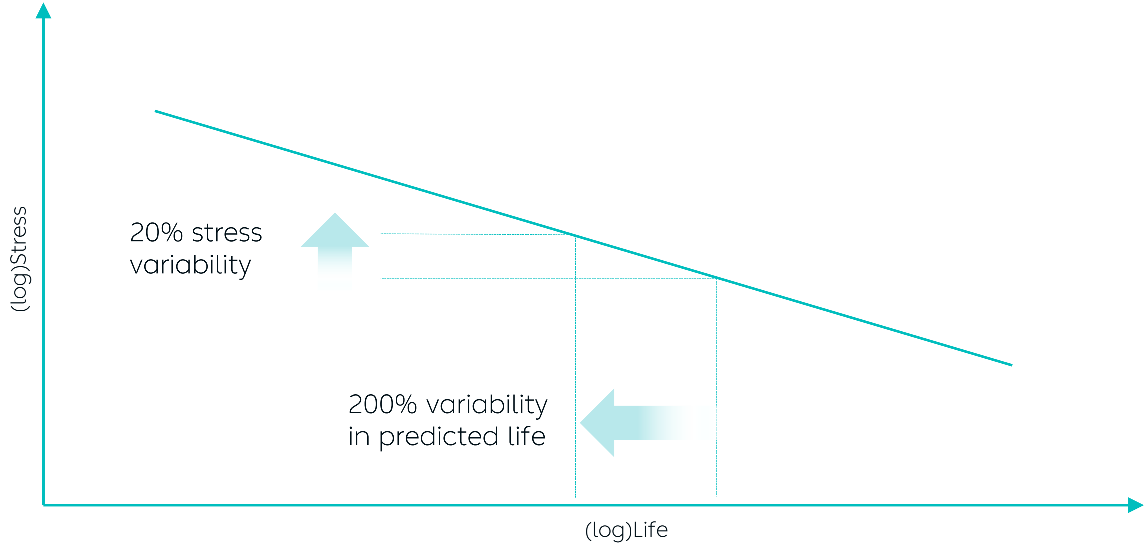
Requires local remeshing

1D SPOT with RBE2 HEAD

Requires local remeshing

Fatigue performance prediction
Predicted life sensitivity

Small variations in recovered forces or stresses might lead **to large variations** in predicted life.



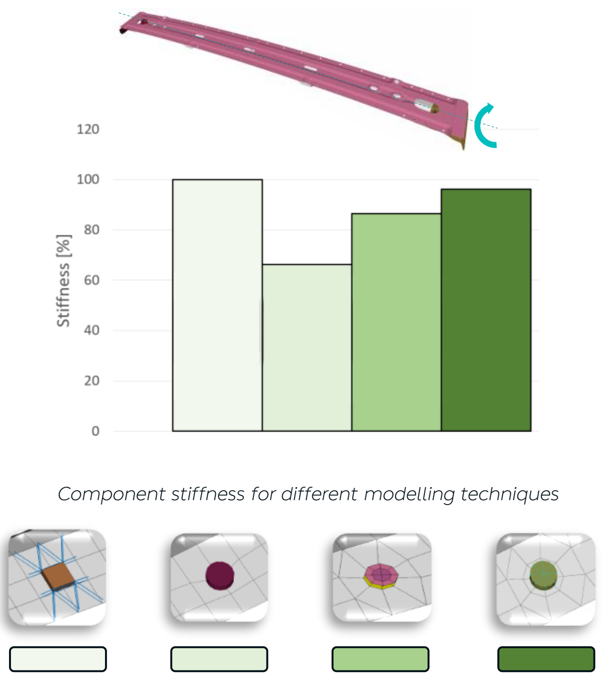
Predicted life sensitivity to the stress changes

Fatigue performance prediction

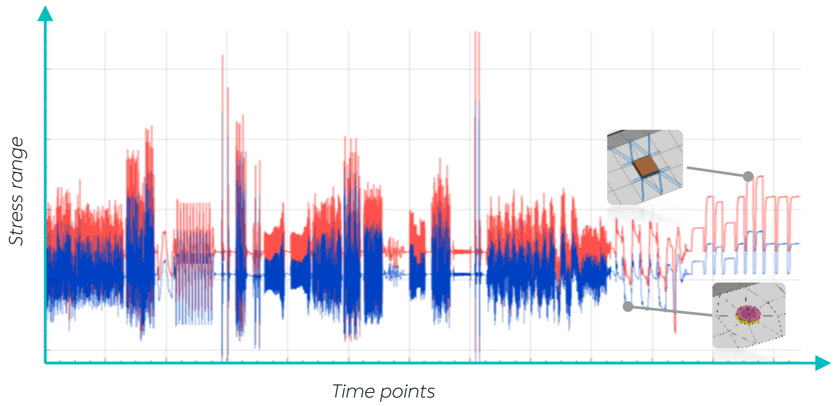
Internal joint forces and moments

Recovered forces and moments might vary depending on the modeling approach.

It is important to **tune the fatigue damage model** to the joints FE representation that is currently being used for making fatigue life predictions.



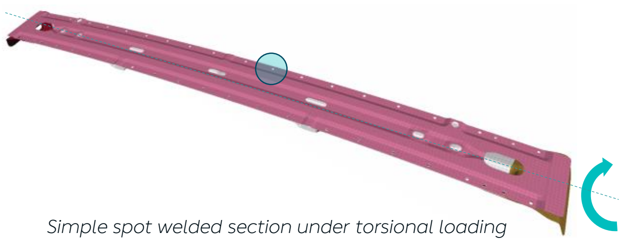
Component stiffness for different modelling techniques



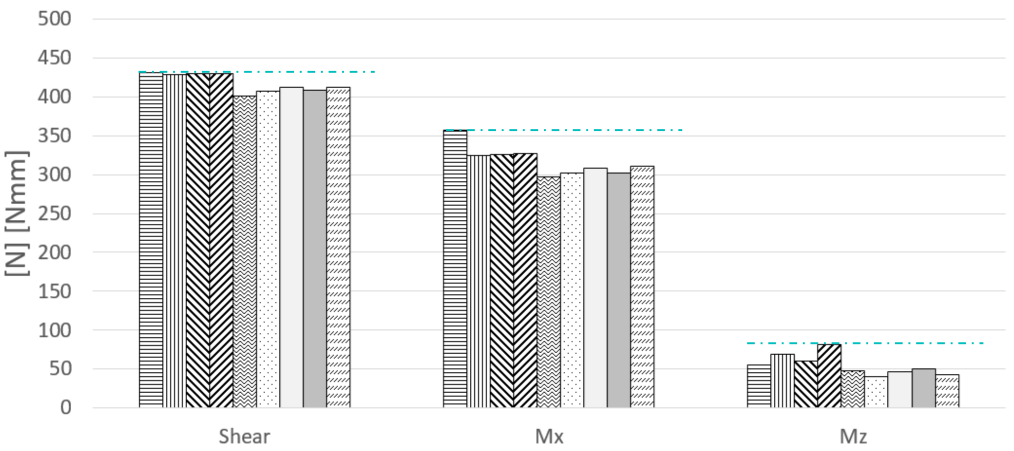
Fatigue performance prediction
ACM2 RBE3's patterns

ACM2 being a mesh-independent technique might generate different RBE3's patterns.

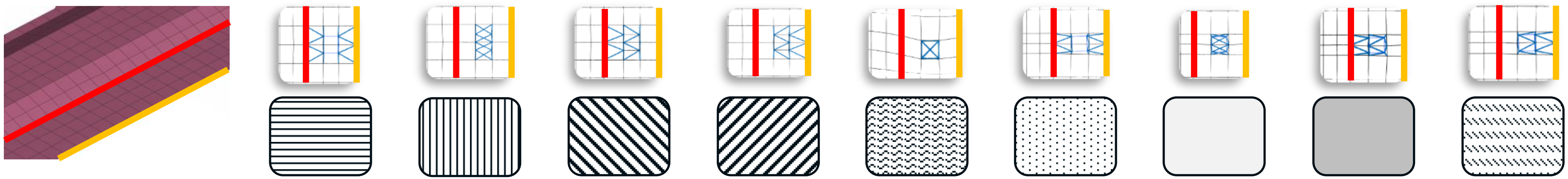
This can influence the **consistency** with which the internal joint forces can be recovered.



Simple spot welded section under torsional loading



Joint forces and moments for different modelling techniques



Thank you

Q&A

- (no questions)

HOTTINGER BRÜEL & KJÆR

Virtual Seminar Series – Tuesday 2, 9, 16 November

Fatigue Simulations of Welded Joints at NIO

Presented by Mr Artur Tarasek
Durability CAE
NIO

Tuesday, November 2, 2021