FE-based Fatigue Simulation of Seam Welds on Car Components and Body

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Zusammenfassung

Wesentlich für die rechnerische Auslegung der Betriebsfestigkeit von PKW-Komponenten und Karosserie ist der Einsatz von Simulationsmethoden zur Berechnung der Lebensdauer (Fatigue Life) der Fügestellen, weil hier, bedingt durch die lokal erhöhte Beanspruchungen, die Wahrscheinlichkeit für Ausfälle am größten ist.

Dieser Beitrag beschreibt die modifizierte Volvo’s Simulationsmethode zur Berechnung von Nahtschweißverbindungen auf der Grundlage der S-N Fatigue-Methode. Anhand der Vergleichen mit Ergebnissen aus den Hardwareversuchen wurde die Genauigkeit dieser Methode überprüft und verbessert.

Introduction

In the modern durability (fatigue) design process is the application of the finite element method to predict the fatigue life of the car components and body structure at an early design development stage.

Fatigue simulation based on realistic loading histories permit structures to be optimised for fatigue life without the need for expensive and time-consuming testing of a series of prototypes.

Welding is an effective and economical method for making structural joints between metal parts. Even in well-designed structure, it is often the welded joints that that are most likely to fail by fatigue. Therefore, an assessment of the fatigue life of such structure must place a high priority on the evaluation of the durability of the welds.

Spot welds and seam welds (Fig. 1) are very commonly used in the automotive industry in the fabrication of all manner of the components and body structures.

In this paper the fatigue simulation methods are presented to assess the fatigue life of the seam welds at the vehicle components and body structure.

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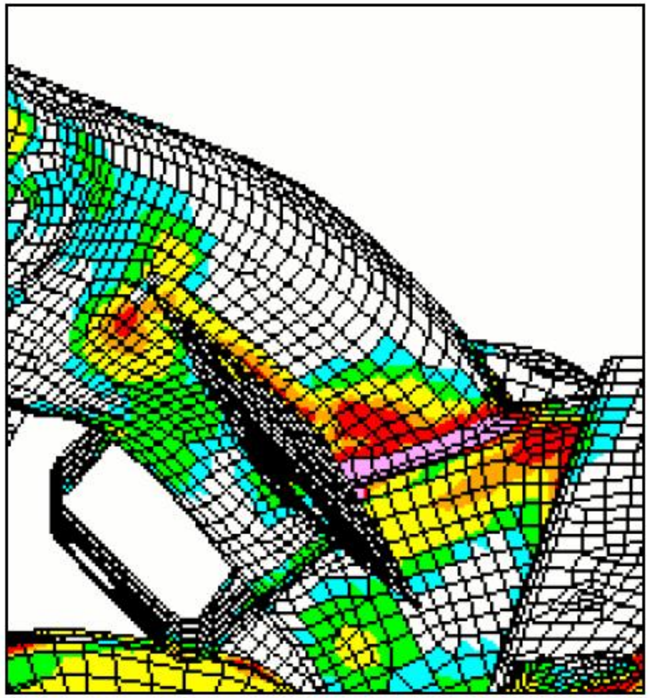
- Passenger Car Subframe



Crack location

Figure 1: Crack at a seam weld (Source : FEM FAT)

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FE-based fatigue simulation

The fatigue strength of the welded joints, is general much less than that of the parts which are welded together. There are a lot of reasons for this:

- Welding introduces geometric features, leading to a stress concentration. The stress will be highest at the toe of the weld, and the shape in this area may not bw well controlled.
- The welding process will very often produce defects which can act as crack initiation sites: slag inclusions, imcomplete fusion, porosity.
- In the heat affected zone (HAZ) where the parent material has been heated to a high temperature and allowed to cool fairly rapidly. This may cause major changes to the microstructure and properties in this region.

All the methods described in this paper are based on characterisation of the fatigue behaviour of the welded joints themselves, in the form of S-N (Stress-Life) curves. These curves incorporate all the effects of defects, residual stresses, notches, and material changes are introduced when the weld is made.

On typical S-N based method for fatigue life prediction of seam welds is described in the British Standard BS7608 /1/.

FE-based fatigue simulation

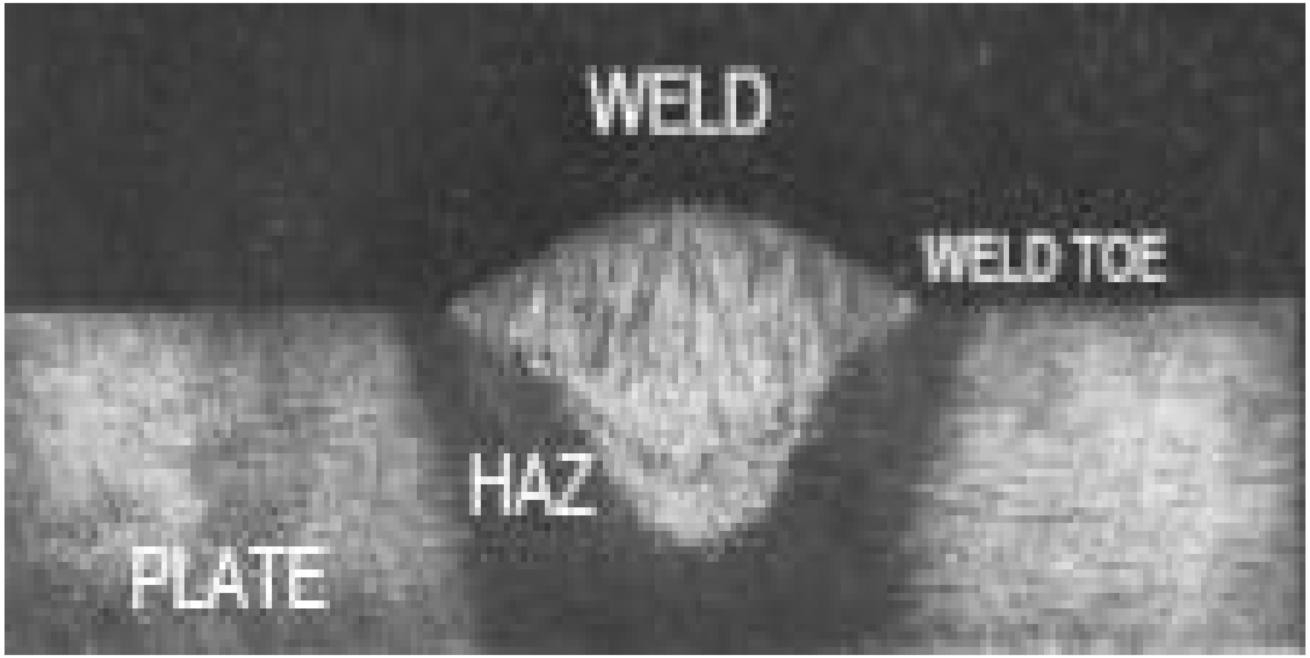

Figure 2: Cross section of a weld

FE-based fatigue simulation

On typical S-N based method for fatigue life prediction of seam welds is described in the British Standard BS7608 [1]. This method is initially developed for application of civil engineering structures designed from thick plates and beams.

The main steps in a BS7608 fatigue analysis are as follows:

1. Choose a weld class for each joint, or part of a joint based on
   a. joint geometry
   b. the loading direction
   c. the likely failure location
   d. the type of weld (full penetration etc)
2. Determine the required stress history due to the loading
3. Calculate the life:

a. rainflow count the stress history
b. use S-N curve for the appropriate weld class
c. use Miner’s rule with small cycle correction to calculate damage and life
d. apply size effect correction (for plates > 16 mm only)

4. Assess the validity of the results

FE-based fatigue simulation

The essence of the stress determination is that you need to find the structural stress at weld toe, but neglecting the detailed effect of the stress concentration. One simple approach that gives satisfactory results for welded sheet structures is to create a mesh from thin shell elements, and the weld is modelled as a row of shell elements with their centroids at the location of the weld toe (Fig. 3)

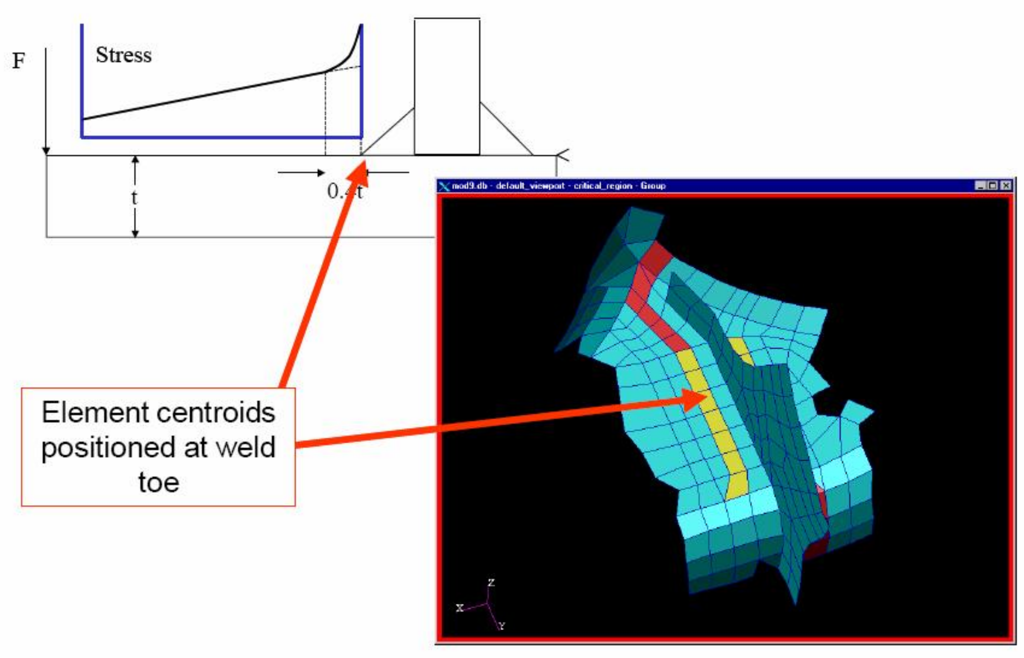

Fig. 3: Mesh for seam weld /1/

FE-based fatigue simulation

Fig. 4 showed results for an automotive suspension subjected to a simple loading. Where there is multi-axis loading , a multiaxial assessment should be caried out. There is a requirement in BS7608 that the principal stress directions should not very by more than 45 degrees. If this limit is exceeded, the analyst will have to exercise some judgement as the most appriote method.

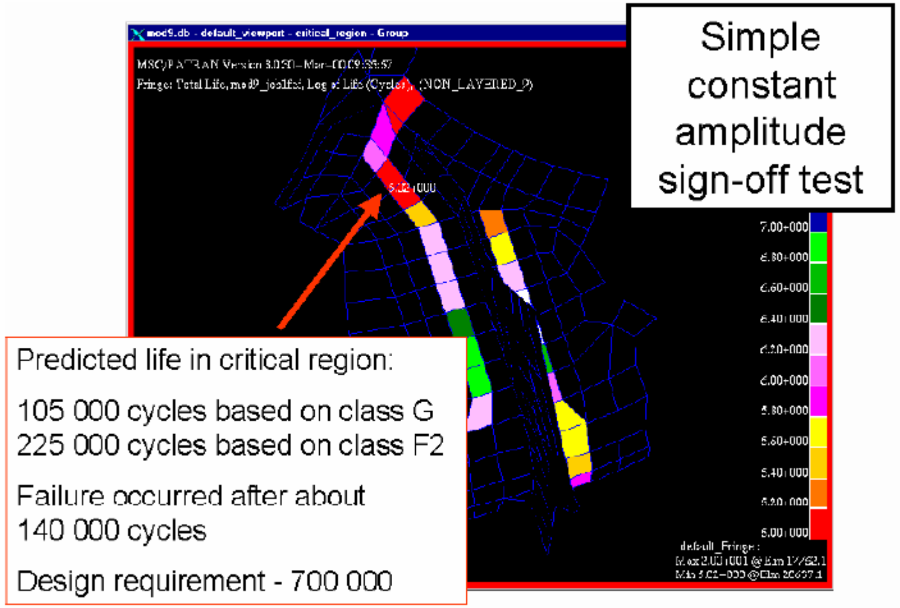

Fig. 4: Analysis results for an automotive suspension component /1/

FE-based fatigue simulation

BS7608 method is not popular for automotive applications, for the following reasons /1/:

- It was mainly developed for thick sheet structures, whereas the majority of automotive join sheets of thickness 3 mm or less.
- Weld classification systems designed for civil engineering structures such as bridges can be difficult to apply to many automotive structures where different geometries may be seen.

A new method was developed at Chalmers University in Gothenburg, Sweden, at the behest of the VOLVO Car Coporation for simulation of the seam welds on body structure. The method was originally developed /3/ was based on similar concept to spot weld method. In this original concept, structural stresses at the weld toe were calculated based on the nodal forces acting on the weld toe elements. The method has been refined and modified to use node-element- stresses at the weld toe /4/.

FE-based fatigue simulation

The original Volvo‘s method has been implemented in FE-Fatigue /2/. This method has been developed specially for automotive components welded from thin sheets (1-3 mm thickness). It can be summarised briefly as follows (Fig. 5):

- The weld sheets are modelled by thin shell elements. The element thickness are equal to the plate thickness
- A row of nodes should be positioned adjacent to the each weld toe
- The weld bead should be modelled using 4 or 3 shell elements. The thickness of this element should be equal to that of the effective weld throat
- The element representing the part of the plate immediately adjacent to the weld toe must be 4 noded element. These are elements from which the stresses are used for the fatigue calculation, so it is particularly important that these are the correct type and of good shape. The element length should be about 5 mm
- Element normals should be aligned within the individual sheet metal parts being joined. The element normals for weld elements must point outwards from the surface to the weld bead.

FE-based fatigue simulation

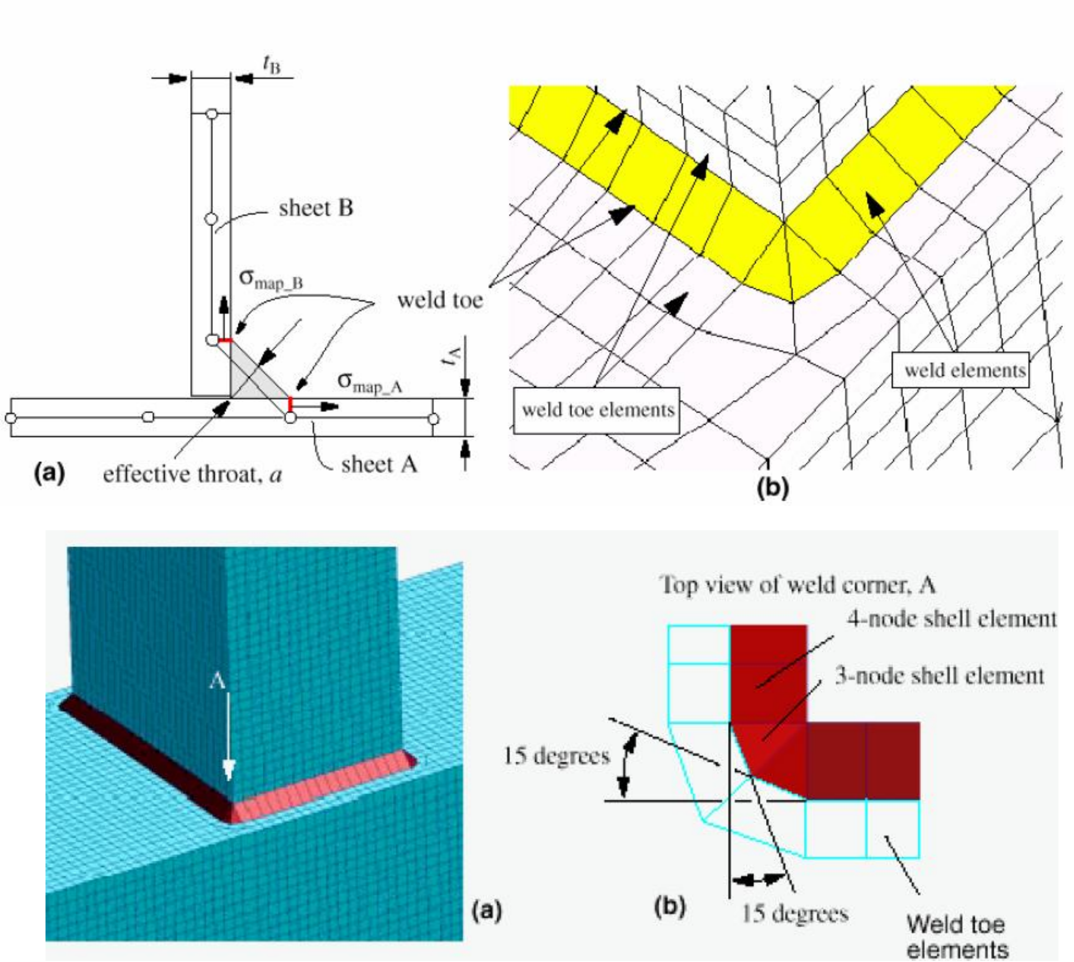

Fig. 5: Seam weld modelling of simple T-joint /2/

FE-based fatigue simulation

Fig. 6 shows a fatigue life calculation process as follows:

1. FE Simulation
   - Calculation node-at-element stresses at weld toe subjected to loading histories

2. Fatigue Simulation
   - Extract top and bottom stresses to abs. max. principal stresses
   - Static or modal superposition of stresses
   - Rainflow counting, mean stress correction, linear damage summation
   - Results report for shortest-lived calculation point at each weld node

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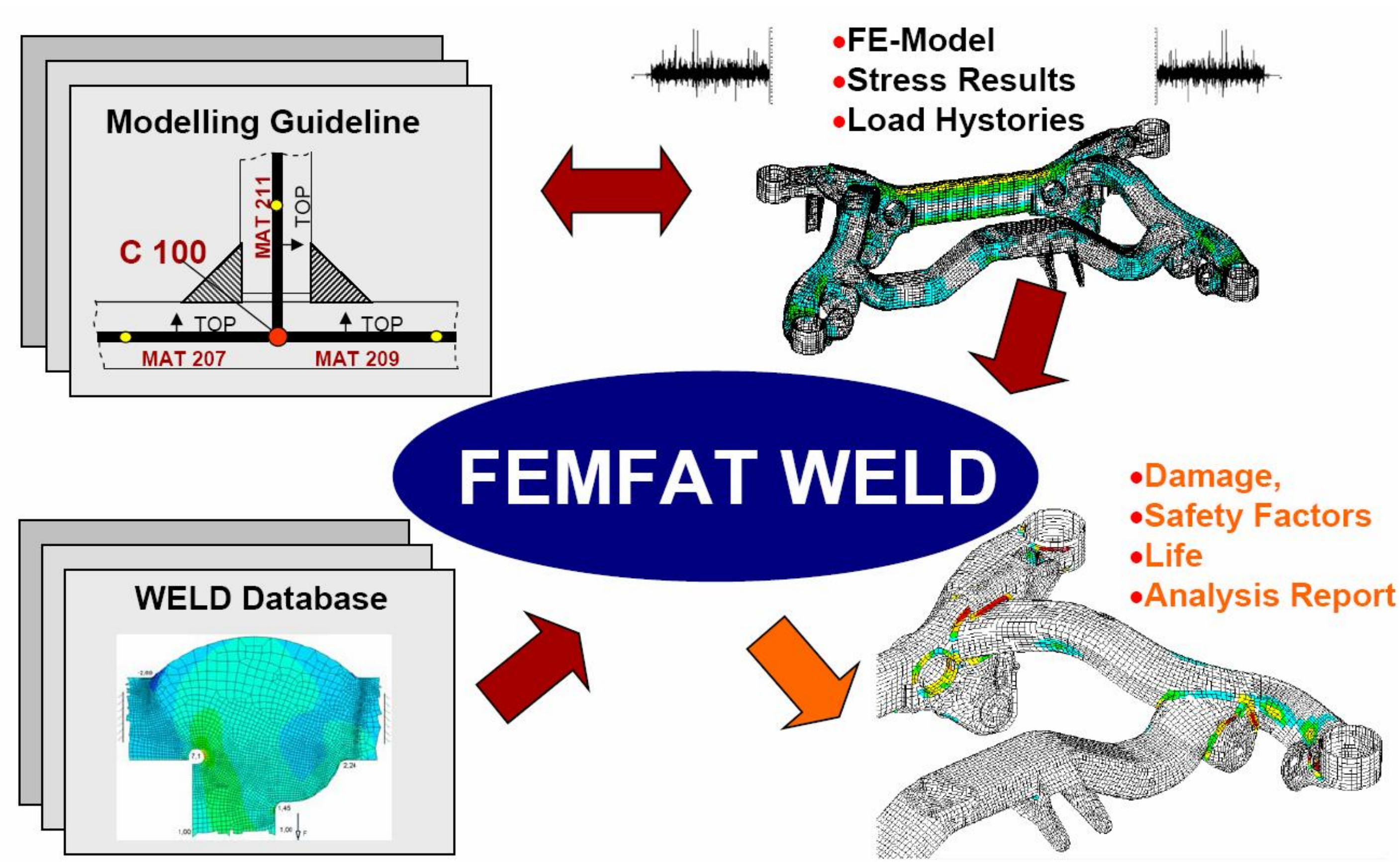
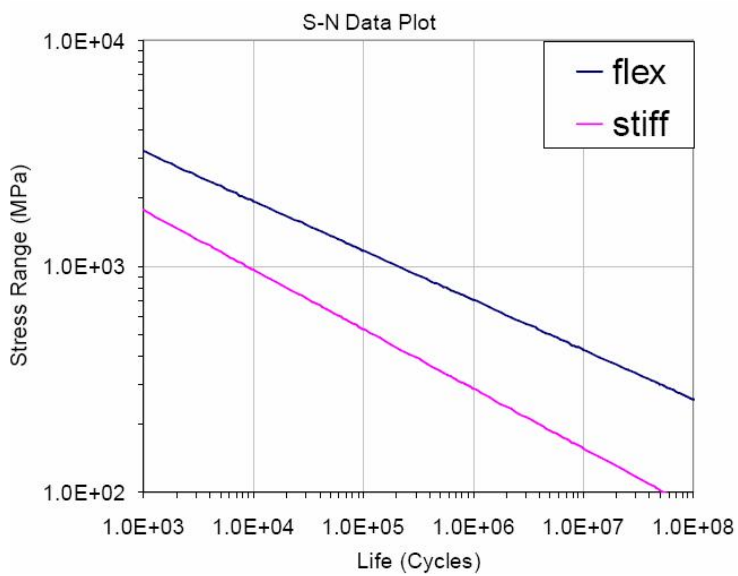
FE-based fatigue simulation



Applications

The finite element fatigue was performed on the rear subframe. The simulation results are compared to test results. The firts results showed very bad correlation. In general, the fatigue simulation provided a very long life of the seam welds.

The poor correlation could be attributed to the fact that the fatigue life were calculated based on two different S-N curves: flex and stiff S-N curves. The flex S-N curve for when the weld is bending. The stiff S-N curve for when the weld is in tension/compression.

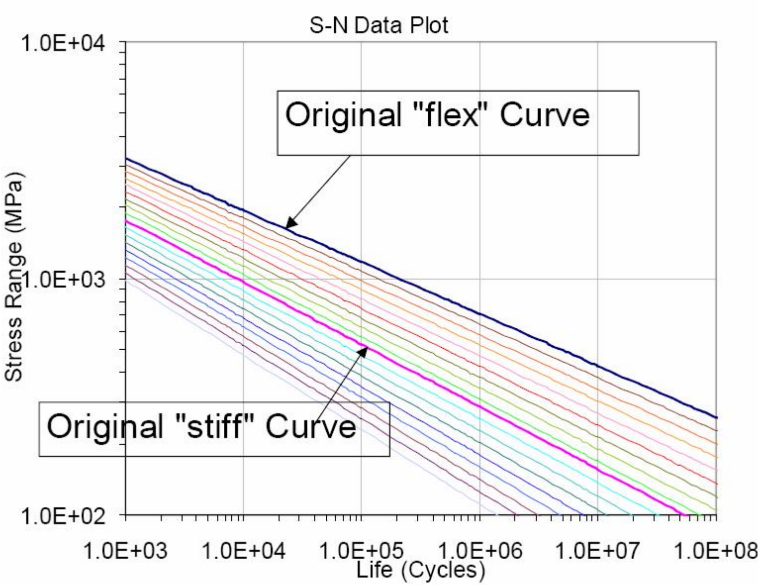


Applications

The fatigue software determines which curve to use for a particular weld, by calculating a flexibility ratio r . This is a ratio of bending and tension/ Compression stress in the weld.

- r =< 0.5 : stiff S-N curve assigned
- r > 0.5 : flex S-N curve assigned

To get good results a range of the S-N curves were created



Conclusions

The fatigue life simulation of the seam weld on body structures can be carried out by using the modified VOLVO‘s method.

This method based on a generic S-N curves leads to inconsistent results (poor correlation to test results).

In order to get good results a range of S-N curves was used.

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