AN APPROACH TO THE EFFECTIVE NOTCH STRESS CONCEPT TO COMPLEX GEOMETRY WELDS FOCUSING ON THE FE MODELING OF WELD ENDS

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ABSTRACT – Automotive structures such as axles of motor trucks are sensitive to fatigue loading due to their construction and loading conditions. The welded components that form the mid-series rear axle under investigation are categorized as thin-walled, with structure thicknesses 1.5<t<15mm. This fact makes their influence dominant for the durability of the structure in addition to the operational loading conditions.
In more detail, the fracture occurs at the weld ends, an area difficult to model and –to the author’s knowledge– with no literature available offering ways to treat such cases. An approach is attempted in this paper adapting the Effective Notch Stress Concept to this complex case, focusing on the modelling techniques and the element number decrease concept using ANSA. Comparison of numerical stress-strain results with experimental ones determined on an own test rig under monotonic and cyclic loading confirms the accuracy of the modelling technique used. The proposed modelling technique can be transferred to various components providing similar weld-end geometries (and failure under operational loading) in order to assess the stress-strain behaviour and fatigue life in an early stage of development where no prototypes are available.

TECHNICAL PAPER -

1. INTRODUCTION

Lightweight design of automotive structures is often based on joining of various components by welds. However, the strength of these structures is commonly limited by the durability of the welds. Various techniques for the assessment of fatigue life of such welded components are proposed by international guidelines [1]. Taking into account that the accuracy of the computational approaches as well as the liability of their respective results depend on the requisite effort and time of the designer and on the complexity of the construction, as shown in Figure 1, it becomes clear why the strength assessment of such structures is still dominated by experimental methods.

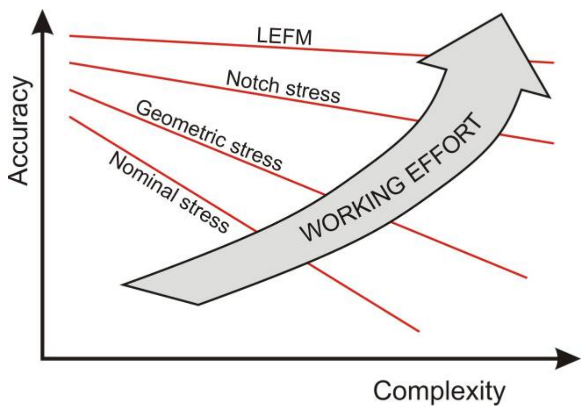

Figure 1 - Qualitative comparison of accuracy and effort for common fatigue assessment methods for welded structures (source: Marquis and Samuelsson [2, 3])

Thus, the need for developing and calibrating calculation methods able to overcome the difficulties encountered at complex geometries with a high accuracy response arises.

Local versus Global Approaches

The most important geometrical parameters of welds are the notch radii of weld toe and root and the depth of penetration at the weld root [4]. Local approaches based on notch stresses or fracture mechanics are established on these characteristics of the weld geometry in contrast to global approaches based on geometric (structural) or nominal stresses, where these effects are put to general categories, leaving out the individual features of the construction. Even though this fact makes them efficient and time reasonable for the early stages in the design process, their capability of accurately assessing the fatigue life shows clear limitations there.

A Step Further

The majority of welds providing starting and ending points fail on theses points (often named "weld ends" of root or toe) under operational loading. Due to the complexity of the geometry and the multiaxial state of stresses which is inserted by this fact, no directions have been proposed yet on how to treat these cases. This paper focuses on the modelling techniques as a first step to confronting complex situations giving special attention to the cost efficiency and the adaptability of the method proposed.

2. THE EFFECTIVE NOTCH STRESS CONCEPT

The basic idea of this concept is that the stress reduction in a notch due to averaging the stress over a certain depth can alternatively be achieved by a fictitious enlargement of the notch radius [5]. Weld geometries can be treated in a uniform manner, taking into consideration only the plate thickness, a factor which divides the concept to the normal and small size approaches with plate thicknesses >5mm (ρ=1mm) and <5mm (ρ=0.05mm) respectively.

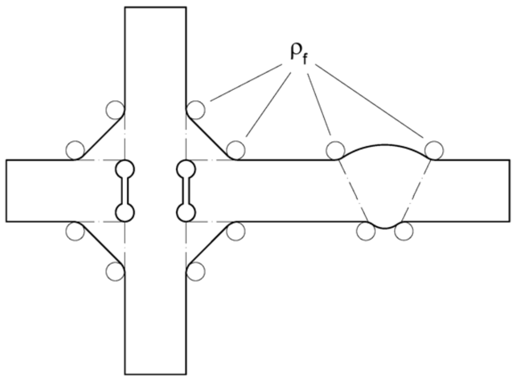

Figure 2 - Fictitious notch rounding (graph according to Hobbacher, 1996) [5]

FEM Modeling

When modelling the weld, an idealized profile is assumed, which is characterized by a constant flank angle θ and the radius of the weld toe and/or root by a reference radius (in the present case of plate thickness >5mm, r_{ref} =1mm).

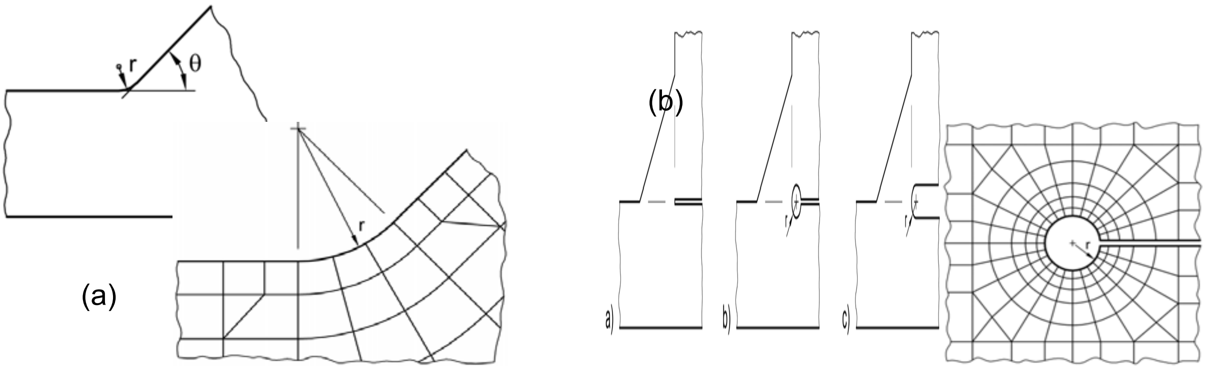

Figure 3 - Typical mesh for the notch stress analysis with elements having quadratic displacement function at the weld toe (a) and root (b) [5]

When dealing with more complex situations, the 2-D figures above can only be referenced as a general guideline. Having in mind that the critical areas of a weld are commonly the weld-ends, these crosshatches of the mesh must be projected also to the critical areas. Paying a closer attention to Figure 4, where an actual component is presented, the difficulty of applying this concept is exposed.

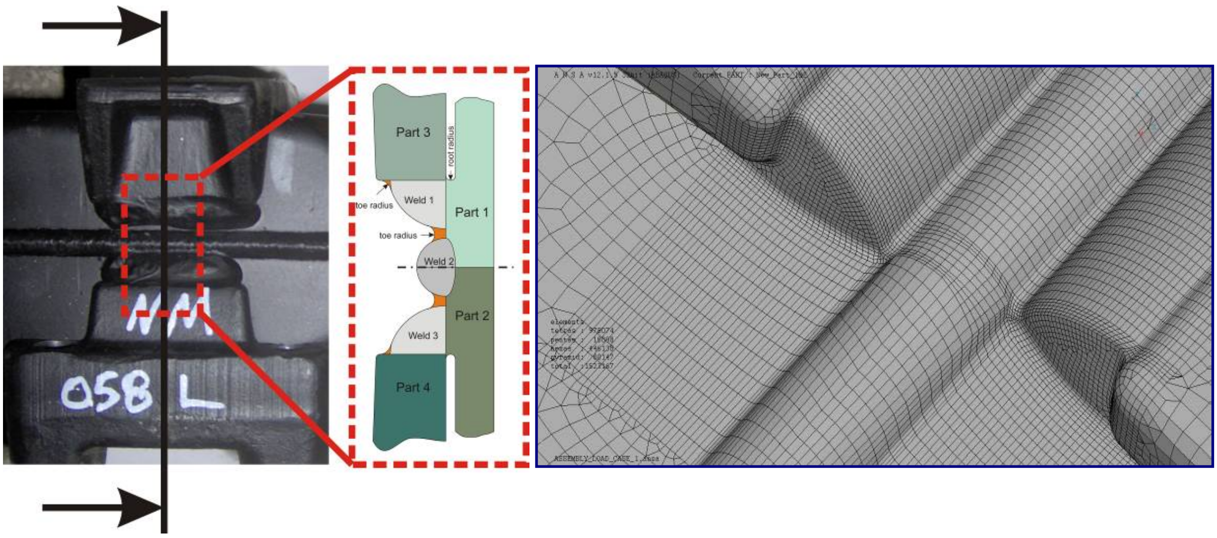

Figure 4 - Example of mesh created for the notch stress analysis with r_{ref} = 1mm

3. GEOMETRY MODELLING

The main concern when preparing the geometry is the proper dividing of volumes, in order for the pre-processor to be able to create mapped solid hexahedral elements. This enables a direct control of the mesh quality and the number of elements created. Special attention is given to the critical areas where a zone of free meshing is allowed only after enough distance has been covered away from the hot spots, in order to jump to a coarser mesh. At this point it is essential to balance the advantage of decreasing the element number to areas away from the points of interest against the substantial increase of elements to the transitional area due to the obligatory creation of tetrahedral elements and/or pyramids.

<u>Hexahedral Only Meshing via Multi-Volume Creation</u>

The weld-end consists of a coon's surface, defined by 3-D curves. In addition, fillets of r_{ref} must be applied to each boundary, creating an intersection area. The challenge is to create mapped volumes, which will ensure ~75% decrease in element number compared to tetrahedral meshing (with the same element length), even with the usage of the advanced tetra-hexa meshing tools offered by ANSA.

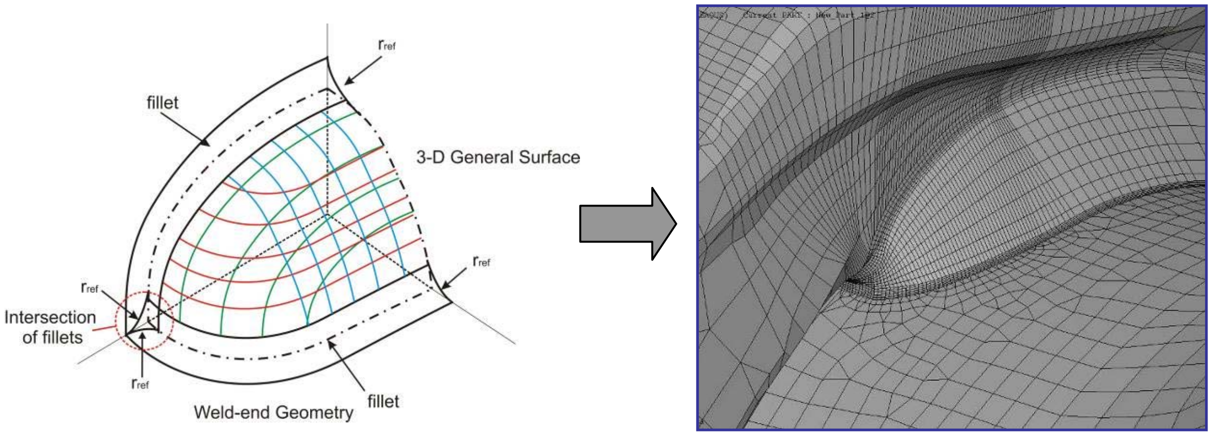

Figure 5 - Hexahedral only mesh via multi-volume creation

Complete Model & Multi-Solver Advantages

A complete model is presented below, which simulates the test rig where different series of experiments where conducted. As a first step the FEA results were compared to the experimental measurements at various locations in order to determine the accuracy of the model.

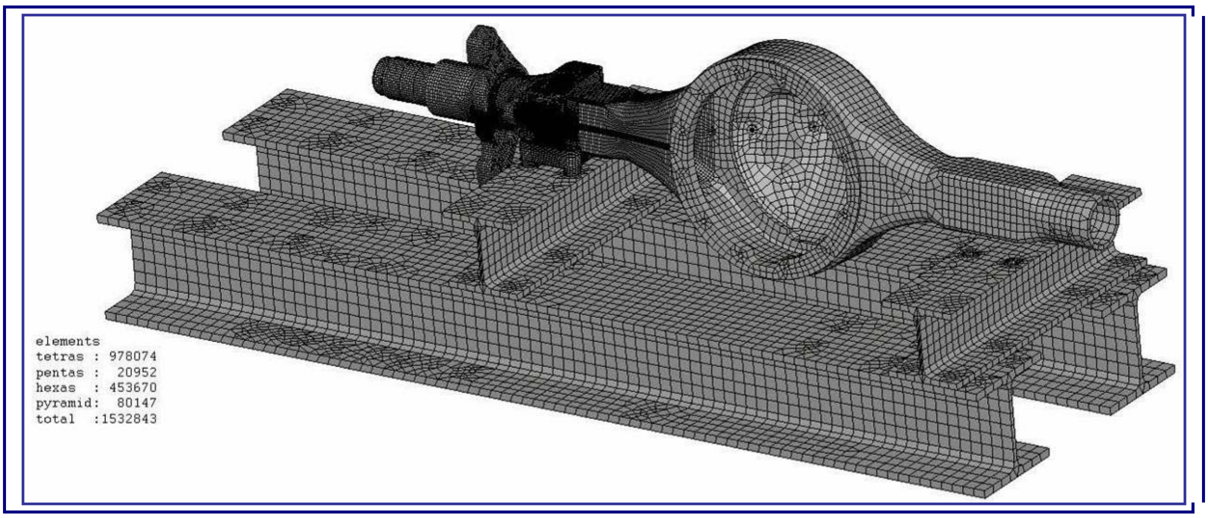

Figure 6 - Complete model – Test rig simulation

The advantage of using a pre-processor with multi-solver support is that the model created is simultaneously sent to different solvers, enabling the direct comparison of their capabilities. This fact narrows down the spectrum of acceptable results and offers a relative certainty of the maximum values, which are to be assessed.

4. RESULTS AND DISCUSSION

To begin with, the stress values calculated by the FE analysis are compared to the experimental measurement results. The distances of the applied strain gauges from the weld toe are taken into consideration, forming a zone of confidence between a best and worst case scenarios. This action is obligatory due to the variations of the weld geometries, which do not permit a firm tolerance of this distance.

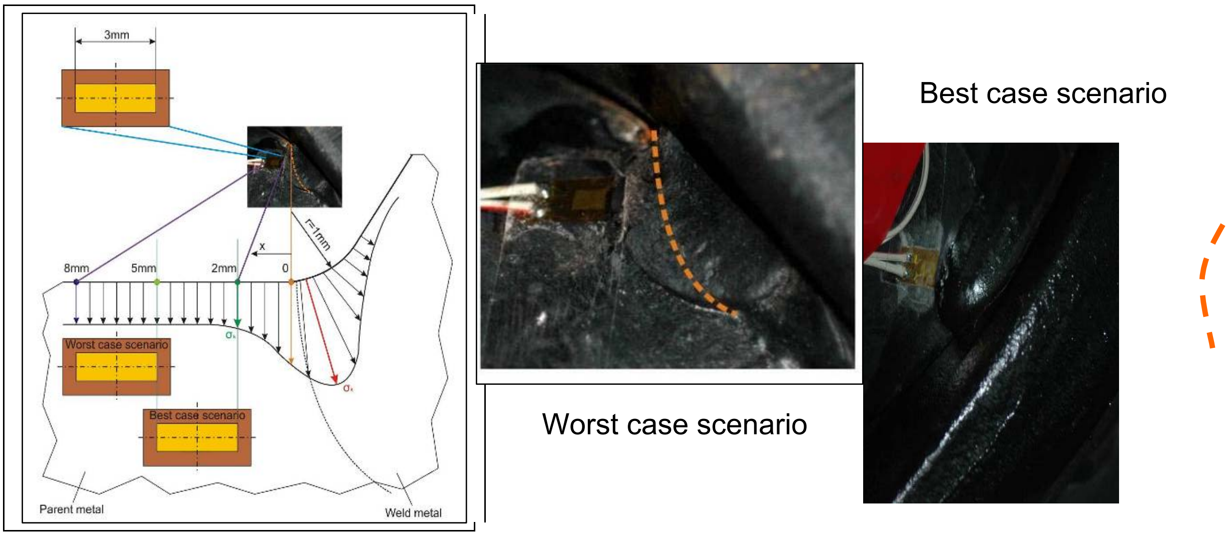

Figure 7 - Factor of distance of the applied strain gages - geometrical variation of weld-ends

The numerical results are then used to quantify the typical stress distribution shown above, via a 2nd order fitting curve. The integrals which are calculated by this curve for the best and worst case scenarios mentioned are compared to the experimental values.

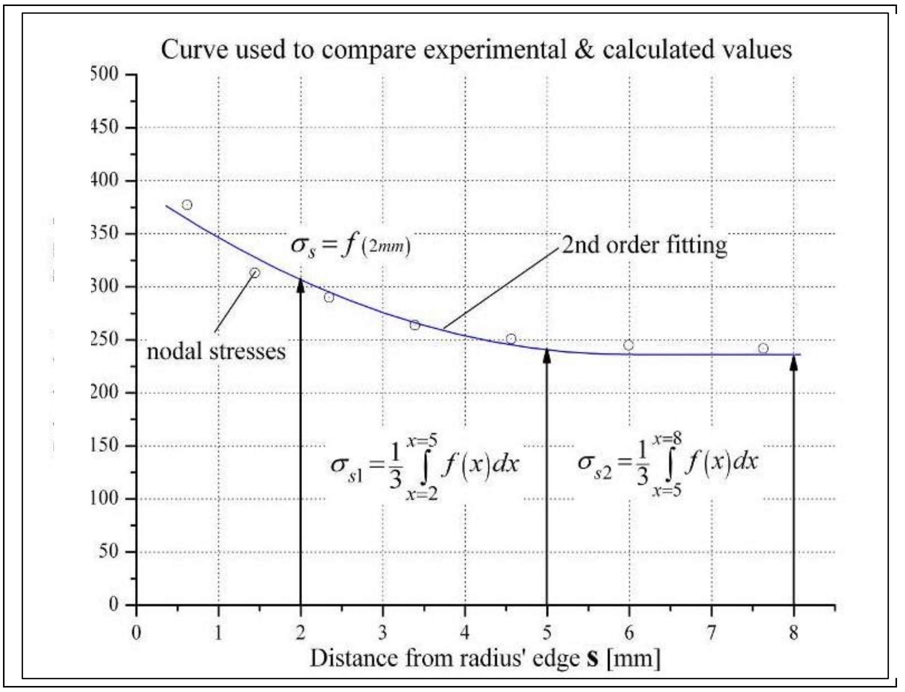

Figure 8 - Curve used to compare experimental and calculated values

The combination of the numerical and experimental results is finally assessed according to the detailed procedure described in IIW guideline [1]. The Wöhler curves (zone of confidence) created are compared directly to the recommended curves. As shown in figure 9, the agreement between the calculated and the intended (experimental) curves for a complex stress field is very well.

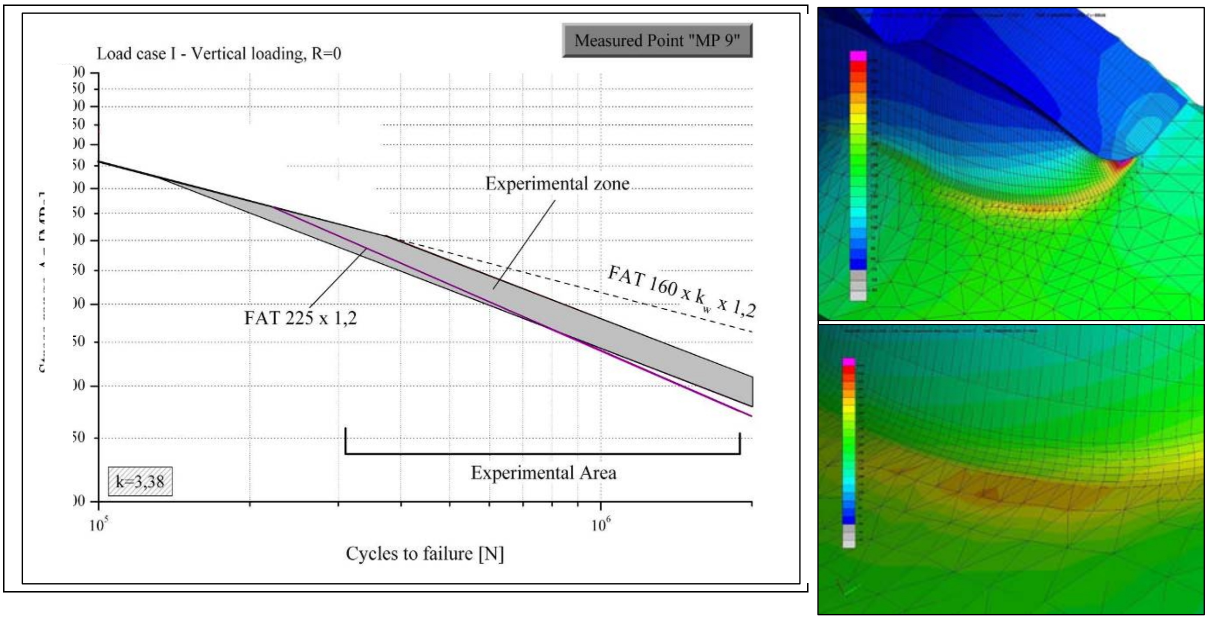

Figure 9 - Comparison between calculated and theoretical fatigue life curves with R=0, for the failure point of load case 1.

5. CONCLUSIONS

The modelling technique proposed in the current paper provides accurate results for complicated stress fields, avoiding as much as possible singularities near critical areas. The number of elements created is considered to be low, offering relatively small solution times, based on the fact that the model consists mostly of hexahedral elements at the stressed regions. The whole procedure can easily be adapted to complex geometries, otherwise difficult to create "light" meshes.
The standardization of the technique is still in progress and is yet to be fully verified. So far the results are encouraging even for multi-axial loading conditions.

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