FITNESS FOR PURPOSE ASSESSMENT OF A STRUCTURAL ALUMINIUM RAILWAY CAR BODY COMPONENT

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ABSTRACT

In its strategic study preceding the launch of the 6th EU Framework Programme the European Rail Research Advisory Council (ERRAC) outlines the vital importance for the railway industry to meet the challenges of doubling the passenger as well as tripling the freight traffic volume within the next 15 years [1]. Key factors which have to be considered to be able to achieve this goal and to attract and satisfy new customers are improved passenger comfort, decreased travelling times and economical use of resources. Therefore on the rolling stock side lightweight construction and modular assembly concepts, especially for passenger car bodies, are constantly being improved. Clearly, operating new vehicle designs under steadily increasing loading conditions both for safety and maintenance reasons requires the application of adapted inspection strategies. In the present study a fitness for purpose assessment has been performed for a car body floor plate of a high speed railway vehicle made from thin walled AlMgSi0.7 (EN AW 6005 T6) extrusions. The extrusions investigated have been MIG welded using AlSi5 wire to form the vehicle floor structure. The assessment takes into account welds with typical defects which can either be caused by the manufacturing process or loading during service. Local material properties such as strength and deformation values, fracture toughness and cyclic crack growth rates of the base and the weld metal as well as of the heat-affected zone are used. By comparison of the local stress strain state (function of geometry, defect state and external loading condition) and the local material resistance weld defects such as lack of fusion, hot cracks or grain boundary openings are evaluated and the consequences for the structure are assessed.

1 INTRODUCTION

Today, the service life assessment of welded structures is normally based on the properties of the weakest material zone in combination with the assumption of an absolutely defect free material. Yet, possible failure of welded components strongly depends on the local material resistance, defect state and stress strain state which represent the basic input data for the fracture mechanics fitness for purpose concept. This concept allows to derive critical defect sizes (caused by deficiencies in the manufacturing process or by service loading) and necessary inspection intervals to ensure safe component operation. In the present study the fitness for purpose concept has been applied to MIG wire electrode welded aluminium extrusions (see figure 1) of a high speed vehicle car body floor structure.

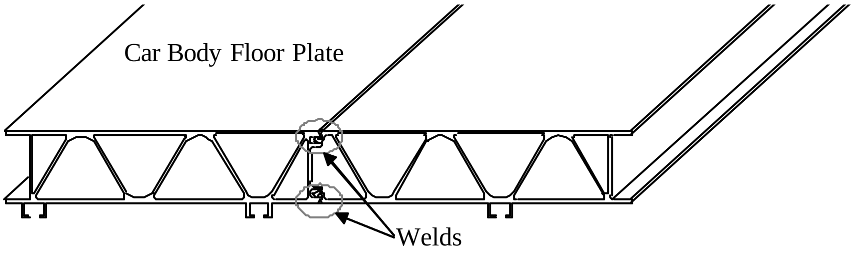

Figure 1: Welded aluminium extrusions with longitudinal weld in a car body floor structure.

For the analysis the following steps have been performed:

- Derivation of a representative structural model for the fracture mechanics assessment,
- Characterization of the specific material properties in the weld joint by conventional and fracture mechanics tests,
- Comparison of the local stress strain state (function of geometry, defect state and external loading condition) and the local material resistance.

First, the position, size and detectability of typical defects in the welds caused by the welding process were studied using different NDT methods. As a consequence of the complex geometry in the floor structure it was not possible to separate the indications from geometry and real defects in a reliable way. Conservatively through-thickness cracks in the weld metal (WM) or the heat-affected zone (HAZ) have been assumed (see figure 2).

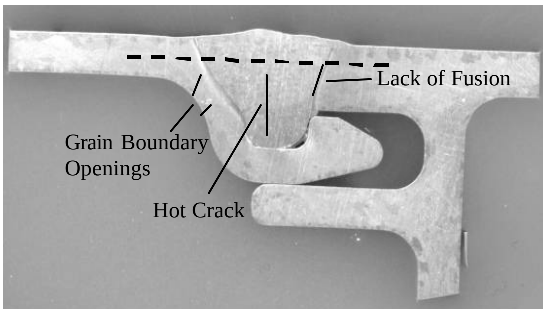

Figure 2: Position of defects representing hot cracks, lack of fusion and grain boundary openings.

2 SPECIFIC (LOCAL) MATERIAL PROPERTIES

2.1 Strength and deformation values

The local material properties have been determined using results of tensile tests with miniature specimens extracted from and parallel to the actual weld (the position of the specimens is indicated by the dotted line in figure 2). By this means strength and deformation property values specific for the base metal AlMgSi0.7, the weld metal AlSi5 and the heat-affected zone shown in figure 3 could be quantified. The strength of the weld metal and the heat-affected zone drops significantly in comparison with the base metal. In case of the yield strength $R_{p0.2}$ only 50% of the base metal strength is reached. At the same time the elongation at fracture A_{10} as a measure of deformation capability of the weld increases.

2.2 Fracture mechanics properties

The fracture mechanics properties under quasi-static and cyclic loading were determined using center-cracked tension panels (CCT) extracted perpendicular to the weld. For the quasi-static tests cracks have been extended to a length of $2a_0 = 35$ mm under cyclic loading. The force (F), the elongation of the specimen (V_{LL}) and the crack mouth opening (V_{CMOD}) have been measured. Stable crack growth was determined using a potential drop method. The results are summarized as J-Δa curves in figure 4. All specimens show a fully plastic behaviour and stable crack growth with lower crack resistance for the base and weld metal. According to ASTM E 1820 (1999) physical (J_i) and technical (J_{IC}) initiation for stable crack growth was determined.

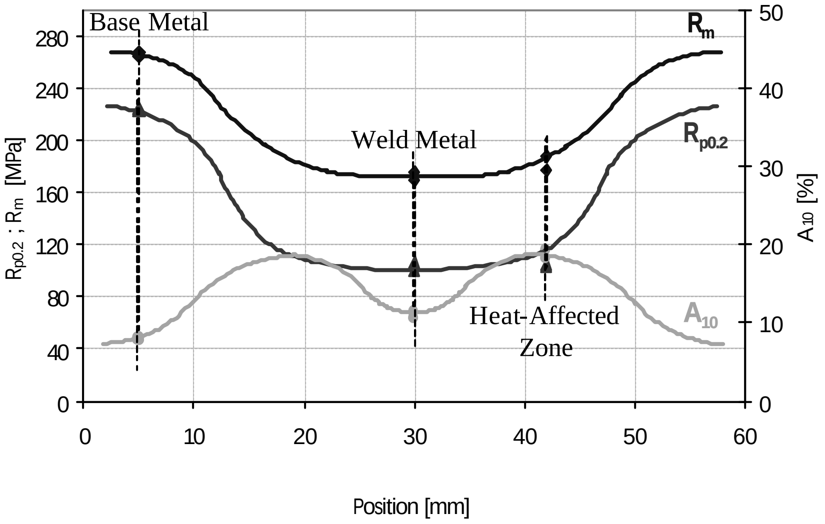

Figure 3: Distribution of strength and fracture strain for MIG welds in EN AW 6005 profiles.

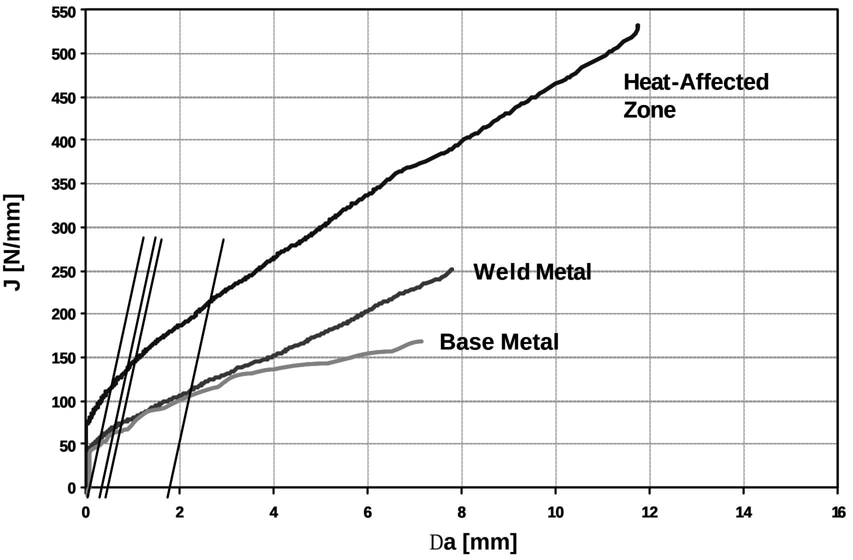

Figure 4: Crack resistance curves for different crack positions.

Crack growth rates under cyclic loading have been determined according to ASTM E 561 (1998). Starter cracks of 6mm were positioned in the center of the WM and the HAZ of transverse welds in CCT-specimens respectively. The crack growth has been determined optically on both sides of the specimens. The results are shown in figure 5. The intersection of the Paris region with a lower bound of $da/dN = 10^{-7}$ mm/load cycle leads to conservative threshold values ΔK_{th}.

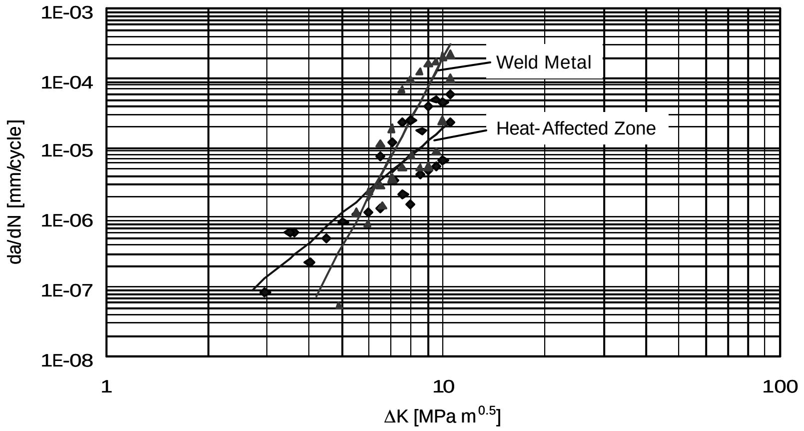

Figure 5: Crack growth rates for cracks in the WM and the HAZ.

3 COMPARISON OF MATERIAL LOADING AND MATERIAL RESISTANCE

3.1 Static loading

For the assessment of structural behaviour under quasi-static loading conditions specimen tests with defects in transverse welds are evaluated. From these results gross section stress / crack opening diagrams for defects in the weld metal and the heat-affected zone were derived. In figure 6 the physical and technical initiation values for stable crack growth as well as the yield strengths of the different weld zones taken from the local material tests are shown. The initiation of stable crack growth lies in the region respectively below the experimentally determined yield strengths.

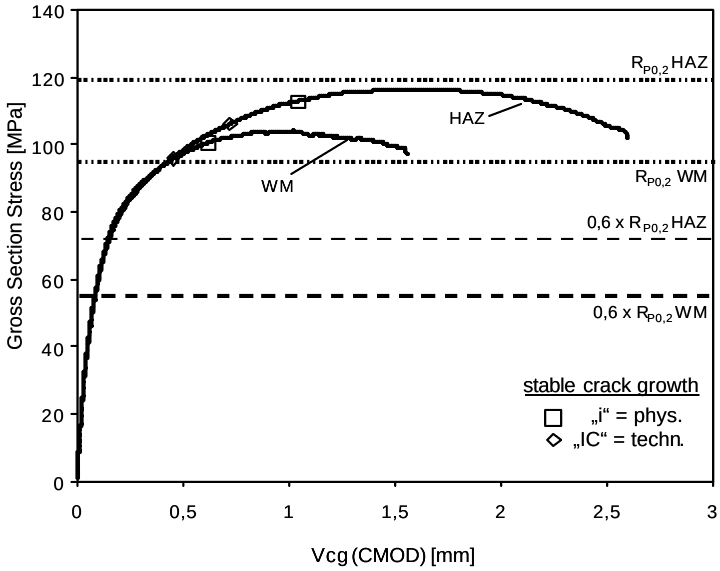

Figure 6: Gross section stress / crack opening diagram for cracks in the WM and the HAZ.

Considering an additional safety factor of 0.6 of the yield strength of the weakest material zone (weld metal) the experimental results show that a stable crack growth of an existing through thickness crack and a 2a/w-ratio of 0.35 (equivalent to a crack length of 35 mm) is only possible if a load of 0.6 x $R_{P0,2}$ is exceeded.

3.2 Cyclic loading

For the fitness for purpose assessment under cyclic loading the calculated defect and load dependent ΔK-values were compared with the local ΔK_{th}-values of the different zones. For the evaluation a structural model with different crack orientations was used (see figure 7); the influence of position and size of the crack on ΔK was investigated in a parameter study.

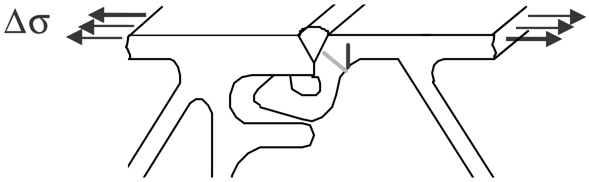

Figure 7: Structural model with grain boundary openings orientated in 45° and 90°.

The applied stress was taken from a FE analysis of a load case defined by the vehicle manufacturer. In this assumed conservative load case a vertical impact of 1,3g is superposed with an aero dynamical pressure impact caused by vehicles passing in a tunnel. The resulting cyclic stress $\Delta\sigma$ was 4.6MPa. The calculated ΔK-values as a function of the defect size are given in figure 8.

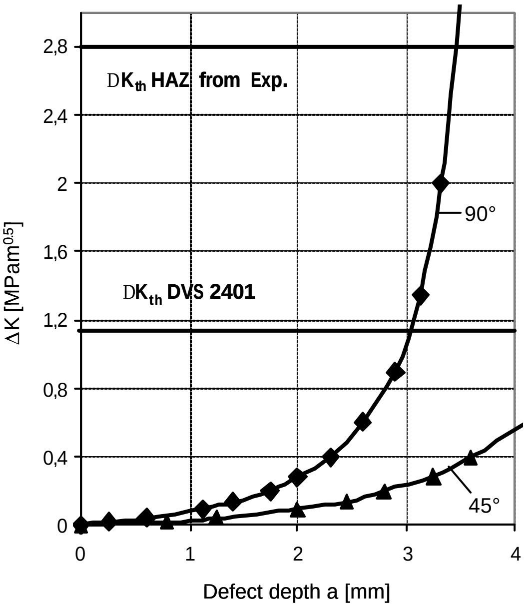

Figure 8: Calculated stress intensity factors as a function of defect depth.

From comparison of the experimentally determined threshold value ΔK_{th} for the heat-affected zone and the more conservative threshold value ΔK_{th} taken from the German regulations, published document DVS 2401 [2], it can be seen, that crack growth will not occur for cracks smaller than 3mm.

4 CONCLUSIONS

The fitness for purpose concept was applied to a welded floor structure of a high speed railway car body. Together with the characterization of the mechanical properties the fracture mechanics approach allows for a quantitative evaluation of defects which occur due to the manufacturing process or during service. The local stress strain state (function of geometry, defect state, external loading condition) and the local material resistance have been determined for the base metal AlMgSi0.7 and the different zones of the weld. The influence of the defect size of hot cracks, lack of fusion and grain boundary openings on the load carrying capacities and the lifetime could be quantified. Considering the given loading case and the strength and toughness properties of the material and weld investigated small grain boundary openings of less than 3mm length which could occur as a consequence of excessive heat inputs during welding will not endanger service behaviour.

5 ACKNOWLEDGEMENT

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6 REFERENCES

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