FAILURE ANALYSIS OF WELDED WIDE PLATES USING FRACTURE MECHANICS CONCEPTS

W. Dahl[*], A. Heuser[**], H. Krebs[*]

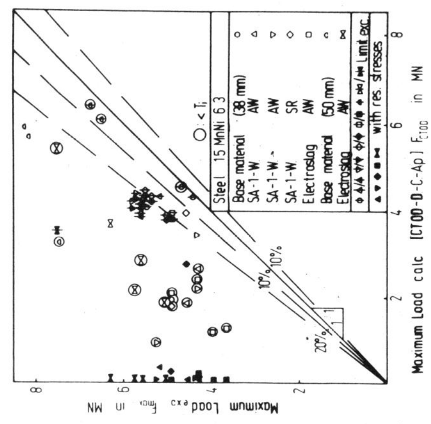
The fracture mechanics failure analysis successfully used for base materials is applied also to welded joints. The complex structure of welded joints with regions of different strength and toughness and the presence of welding residual stresses lead to problems concerning an exact prediction of failure load.
Within the scope of these investigations conventional wide plates containing a welded joint have been tested. The steel investigated was a microalloyed, fine grained type 15 MnMi 6 3. The wide plates had a width of 350 mm and a thickness of 30 mm. The specimen type was center notched tension (CNT) with a notch length of 20 mm. The notches were located at the fusion line of the heat affected zone (HAZ), which is usually considered as the zone with the most unfavourable toughness properties in the welded joint.
The wide plates were tested in the linear-elastic, the fully plastic and the transition temperature range. The maximum allowable loads were calculated with the plastic limit load concept, the CTOD-Design-Curve-Approach, the CEGB-Defect-Assessment-Procedure (R6-method) and the EPRI-method. The suitability of the different failure concepts was examined by comparison of the calculated and the experimentally determined instability loads. The tested wide plates represent a simple structural component because of their dimensions and the resulting undisturbed state of welding residual stresses.

---

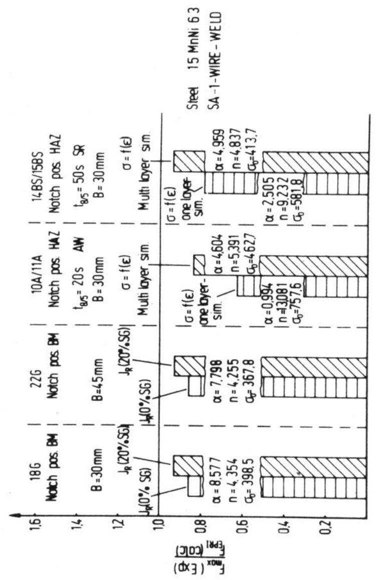
[*] Institute of Ferrous Metallurgy, Technical University Aachen, FRG

[**] now: BASF AG, Ludwigshafen, FRG

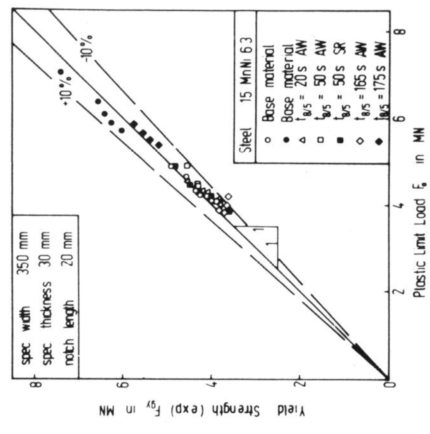
Evaluations done with the plastic limit load concept have shown good coincidence with experimental results. However, scatter in the yield point values has to be considered for a safe prediction of strength controlled failure of the wide plates. A softening of the HAZ, which is observed in high heat input welding, should also be taken into account. Using this concept, brittle fracture must be excluded. Consequently the lowest allowable service temperature for a structure has to be determined separately.
Predictions with the CTOD-Design-Curve-Approach describing toughness controlled failure exhibited safe results in all cases even without taking residual stresses into account. If the limit of application of this concept is reached, a strength controlled failure has to be assessed, e.g. by a plastic limit load analysis.
Application of R6-procedure, which describes strength-controlled as well as toughness-controlled failure, led to a quite reasonable agreement of calculated and experimentally determined maximum loads for all tested wide plates.
Evaluations according to the EPRI-method have shown that also for wide plates containing a defect in the HAZ the instability caused by stable crack growth can be calculated with an accuracy which is comparable to that of wide plates containing a defect within the base material.
Welding residual stresses have to be taken into account when calculating failure loads of welded structures with the help of CTOD-Design-Curve-Approach and the R6-procedure. This is usually done by assuming a constant level of the residual stresses as high as the base material yield point in the whole ligament. By this very strict assumption conservativity in failure prediction becomes extremely high.
For a welded wide plate the actual state of welding residual stresses was measured by the strain gage cutting method in order to assess its effect on failure. The difference in results between considering and not considering the actual state of welding residual stresses in failure analysis may be neglected in this case.



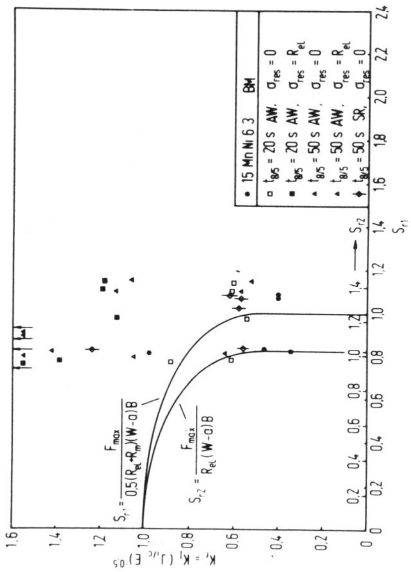
Maximum Load exp F_{max} in MN
Maximum Load calc [CTOD-D-C-Ap] F_{CTOD} in MN
Steel 15 MnNi 6 3
Base material (38 mm)
SA-1-W AW
SA-1-W AW
SA-1-W SR
Electroslag AW
Base material (50 mm)
Electroslag AW
Limit exc. with res. stresses
20%
10%
-10%



Steel 15 MnNi 6 3
SA-1-WIRE-WELD
18G Notch pos. BM
22G Notch pos. BM
10A/11A Notch pos. HAZ
14BS/15BS Notch pos. HAZ
B=30mm
B=45mm
α = 8.577 n = 4.354 $σ_0$ = 398.5
α = 7.798 n = 4.255 $σ_0$ = 367.8
α = 0.994 n = 43.081 $σ_0$ = 757.6
α = 4.604 n = 5.391 $σ_0$ = 462.7
α = 2.505 n = 9.232 $σ_0$ = 581.8
α = 4.959 n = 4.837 $σ_0$ = 413.7
Multi layer sim.
one layer sim.



Yield Strength (exp) F_{gy} in MN
Plastic Limit Load F_0 in MN
spec width 350 mm
spec thickness 30 mm
notch length 20 mm
Steel 15 MnNi 6 3
Base material
Base material
+10%
-10%



$K_r = K_I / (J_{Ic} E)^{0.5}$
$S_{r1} = \frac{F_{max}}{0.5(R_{eL}+R_m)(W-a)B}$
$S_{r2} = \frac{F_{max}}{R_{eL}(W-a)B}$
S_{r2}
S_{r1}
15 MnNi 6 3 BM