# Consideration of the Practical Use of Fracture Mechanics Technology with Particular Reference to Pressure Vessels

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The applicability of FMT [1] to the fracture behaviour of thick walled large scale components made from medium strength steels was studied for the vessels no. 1 to no. 10 listed in table 1 [2]. Except for no. 9 all vessels had been in service for 10 to 25 years. Burst tests as well as failures (no. 1 and no. 9) are considered:

1: fracture during the hydraulic test after repair welding (wall temp $\geq 50^\circ$C)
9: fracture during the hydraulic test in the workshop (wall temp $\geq 35^\circ$C)
2 to 8, 10: burst test at ambient temperature

Apart from no. 1 the fracture started at the tip of cracks which had developed during the manufacturing process or in service. In the cases of no. 6 and no. 10 the cracks were enlarged by additional cyclic pressure at ambient temperature before being bursted.

Table 1 shows specified material properties and the lowest fracture toughness values determined acc. fig. 1. When no valid value acc. ASTM 399-70 T resulted, the maximum loads $F_{max}$ were converted into $K_{Imax}$ by the same method as for $K_{Ic}$. For comparison the nominal stresses together with shape and size of cracks (fig. 2) analogous fracture toughness values for the bursted vessels were obtained, table 1.

The cracks at the hole edges are difficult to be analyzed; an approximate calculation acc. type 3 gives nearly the same results as another approximate calculation published by Liu [3]; a finite element calculation shall throw more light on this question. A sufficient correlation exists for the edge cracks of no. 10 (type 4) and no. 6 produced by cyclic pressure (equivalent to the fatigue cracking procedure with CT-specimens).

No correlation exists for the cracks in no. 2 (in service) and no. 9 (not yet in service, virgin proof test). No. 2 is covered by type 1 and no. 9+) approximately by type 2. In the latter case the crack formation occured in course of the stress relief heat-treatment in the HAZ of a welded nozzle with full penetration. Significantly the final fracture did not start in

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+) C.16, Si.31, Mn 1,64, P.017, S.007, Al.060, Mo.21, Ni.96, V.14, N.008 %

the middle where the "old" crack had its greatest depth with 15 mm, but had left the brittle HAZ (stress relief embrittlement) and arrested in the tough base material. It actually started at the tail, where the "old" crack was only 5 mm deep and had remained in the brittle zone. Even if a depth of 15 mm were used, a fictitious fracture toughness value of only 138 kp/mm$^{3/2}$ would result. The local embrittlement in the region of the crack front which determines obviously the low values of vessels like no. 2 and no. 9 must be attributed to manufacturing and service influences [4]. Only tests following unrealistic overheating and air cooling (table 2) gave for no. 9 a poor $K_{Ic}$, which however was higher than the analogous value for the vessel as calculated from the bursting dates. The remaining difference can be explained by insufficient local embrittlement and size of the test specimens (improbable with regard to the experience with specimens up to 10 T) furthermore by residual stresses. Whether a modification of the theory can reduce the discrepancies shall not be considered here. For no. 9 residual stresses are secondary as they should be relieved due to the crack formation during the manufacturing process. As the (multiaxial) residual stresses in the component cannot be analyzed reliably it is problematic to take them into account.

No comparison is possible for no. 1[x)], where the fracture originated from a tack weld of high hardness (without presence of a crack). If a $K_{Ic}$ = 80 kp/mm$^{3/2}$ (corresponding to no. 9) were used for the crack type 1 a fictitious size of a = 10,7 mm would result. Certainly a crack of this dimension would have been noticed. This case is significant for a fracture originating from a local degradation of toughness due to phase modifications and multiaxial stresses without the presence of any crack. An application of FMT is therefore not possible; theoretically a crack may be initiated at any level of load stress. If the nominal stress exceeds a certain level with sufficient energy stored (with power plants nearly always given) the damage will become catastrophic. The probability that all unfavourable states coincide is naturally low; a statistical analysis will be problematic.

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[x)] C.16, Si.38, Mn.90, Cr.20, Ni.59, Cu.67 %

Adequate high overloading [5] is indispensable if phase embrittlement due to manufacturing and service is not controllable. With these safety precautions vessels with critical states will be eliminated.

## Literature

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