VALIDATION OF SIMPLIFIED FRACTURE MECHANICS METHODS BY TESTING OF REAL COMPONENTS

G. Bartholomé, G. Senski, R. Wellein

To validate simplified calculation methods for circumferential crack (Flow Stress Concept = FSC; Plastic Limit Load = PLL) and for axial cracks (Battelle Approach = BMI; Ruiz-approach = RUIZ) all available experiments on real structural components, especially on pipes, were analysed and evaluated by these methods (460 experiments).

INTRODUCTION

The evaluation of integrity of structural components is often based on the proof of leak before break (LBB). LBB behaviour in pipings constitutes a fail - safe condition. Simplified fracture mechanics are used for the demonstration of LBB. For this the conservative, safe calculation of the critical through wall crack (TWC) length for ductile failure is necessary.

SIMPLIFIED FRACTURE MECHANICS METHODS

For the ductile failure mode simplifed elastic-plastic fracture mechanics concepts are used for circumferential cracks: (FSC according to Bartholomé et al. (1) and PLL according to Roos et al. (2)) and for axial cracks: (BMI according to (2) and RUIZ according to Ruiz (3)).

EVALUATION OF METHODS BY TESTS

To validate the used methods for circumferential crack (FSC; PLL) and for axial cracks (BMI, RUIZ) all available experiments on real structural components, especially on pipes, were analysed and evaluated by the above methods (460 experiments). The methods were adapted by application of correction factors, mainly on the flow stress, to result in conservative (safe) and realistic (as near as possible to the experiments) predictions. The prerequisites for the application of the above methods, the principles for the evaluation of the experiments and the test results are given in references (1) and (4).

RESULTS

Fig. 1 Circ. and axial TWC (FSC, BMI) versus charpy toughness
Fig. 2 Circ. and axial TWC (PLL, RUIZ) versus charpy toughness
Fig. 3 Circ. TWC (ferritic and austenitic material, $a_v > 45$ J, FSC) vs. $R_{0.2}/R_m$
Fig. 4 Circ. TWC (ferritic and austenitic material, $a_v > 45$ J, FSC) vs. t
Fig. 5 Circ. TWC (ferritic and austenitic material, $a_v > 45$ J, FSC) vs. Da
Fig. 6 Axial TWC (ferritic and austenitic material, $a_v > 45$ J, BMI) vs. $R_{p0.2}/R_m$
Fig. 7 Axial TWC (ferritic and austenitic material, $a_v > 45$ J, BMI) vs. t
Fig. 8 Axial TWC (ferritic and austenitic material, $a_v > 45$ J, BMI) vs. Da

CONCLUSIONS

Depending on method (FSC, PLL, BMI, RUIZ), crack orientation (circumferential and axial cracks) and type of material (ferritic and austenitic material) different definitions of flow stresses were established ($R_{p0.2}$ = yield stress; R_m = ultimate tensile strength f_1, f_2 = correction factors):

Material Type	ferritic	austenitic	ferritic	austenitic
Axial Cracks	BMI	BMI	RUIZ	RUIZ
Flow stress	$R_{p0.2} \cdot f_1$	$R_{p0.2} \cdot f_1$	$R_{p0.2} / f_2$	$\frac{R_{p0.2} + R_m}{2} / f_2$
Circumferential Cracks	FSC	FSC	PLL	PLL
Flow stress	R_m	$\frac{R_{p0.2} + R_m}{2}$	$R_{p0.2}$	$R_{p0.2}$

Correction factors:

$$f_1 = 1.7 - 1.2 \cdot \frac{R_{p0.2}}{R_m}; \quad f_2 = \sqrt{0.8 + 0.23 \cdot c^2 / (r_m \cdot t)}$$

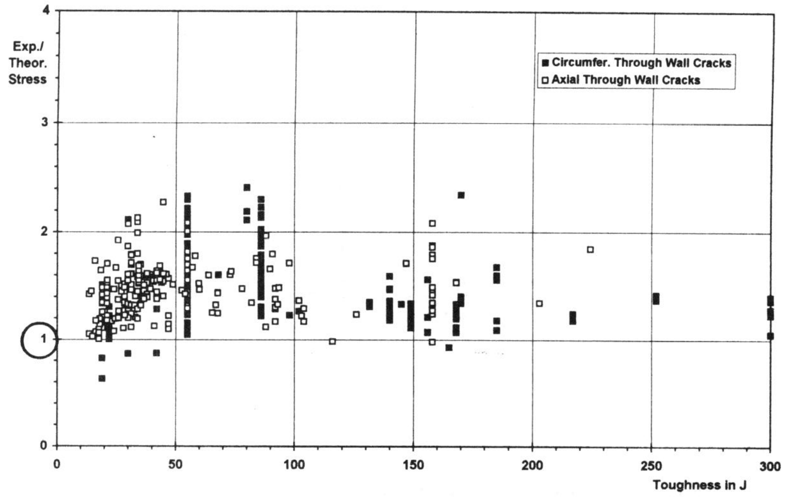
REFERENCES

(1) Bartholomé, G., Wellein, R.
"Evaluation of Components Tests with Analytical Fracture Mechanics Methods (Circumferential Cracks)";
ECF 10, Berlin, 23.09.1994, p. 1317 - 1326

(2) Roos, E., Herter, K.-H., Bartholomé, G., Senski, G.
"Assessment of Large Scale Pipe Tests by Fracture Mechanics Approximation Procedures with Regard to Leak-Before-Break"
Nuclear Engineering and Design 112 (1989), pp. 183 - 195

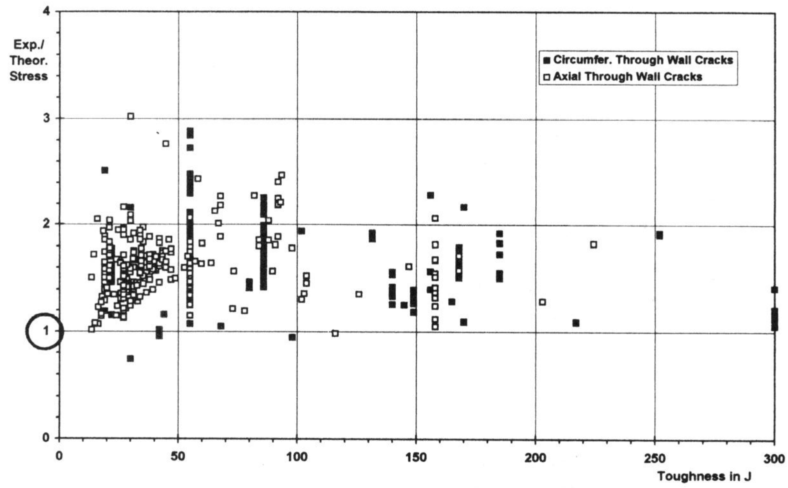
(3) Ruiz, C.
"Ductile Growth of a Longitudinal Flaw in a Cylindrical Shell Under Internal Pressure";
Int. J. mech. Sci., Vol. 20 (1978), pp. 277 - 281

(4) Bartholomé, G., Wellein, R.
"Evaluation of Tests on Pipings with Axial Through Wall Cracks for Verification of Leak-Before-Break Behaviour" (in German)
German Association for Materials Testing, Working Group Fracture Processes, 26th lecture meeting 1994, Magdeburg, 22./23.02.1994, p. 407 - 421



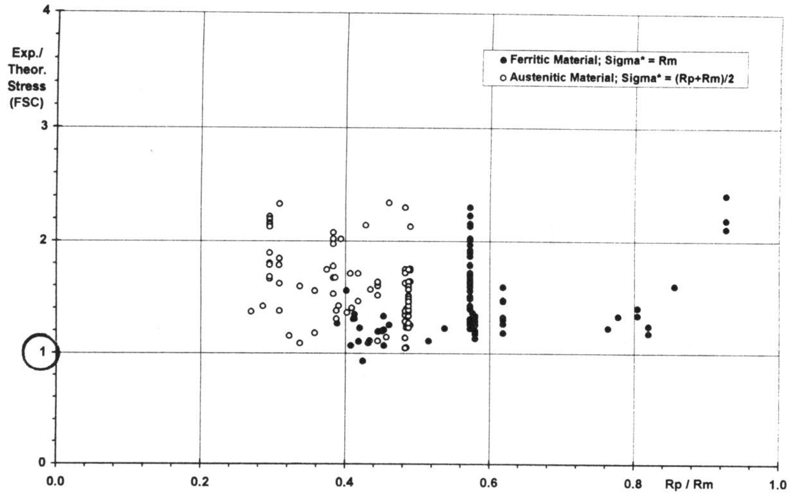
Ratio of Experimental to Theoretical Stress using Flow Stress Concept (FSC) for Circumferential TWC and BMI for Axial TWC in Dependance of Toughness of Material (WM = BM) (SF)

Figure 1



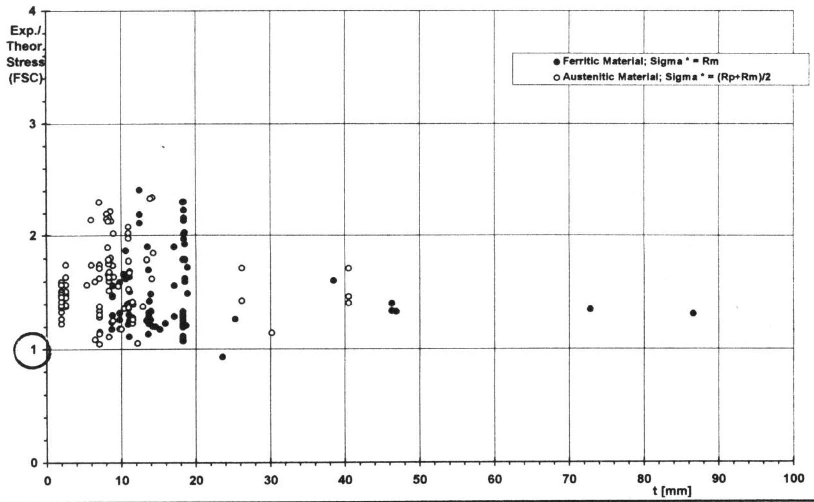
Ratio of Experimental to Theoretical Stress using Plastic Limit Load (PLL) for Circumferential TWC and RUIZ for Axial TWC in Dependeance of Toughness of Material (WM = BM) (SF)

Figure 2



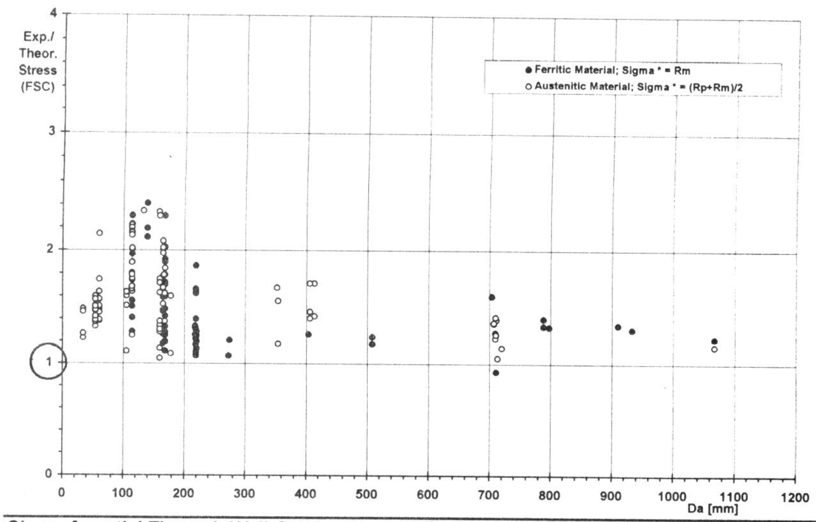
Circumferential Through-Wall Cracks: Flow Stress Concept (FSC)
Using Experiments with Av > 45 J and WM = BM

Figure 3



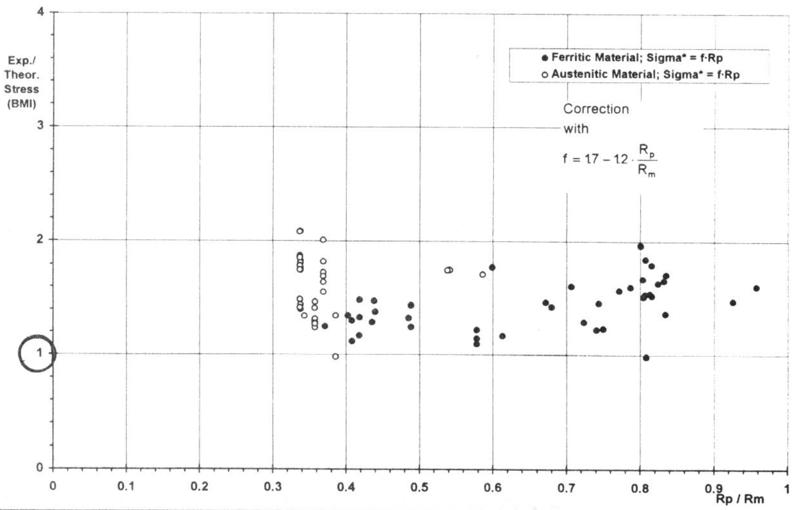
Circumferential Through-Wall Cracks: Flow Stress Concept (FSC)
Using Experiments with Av > 45 J and WM = BM

Figure 4



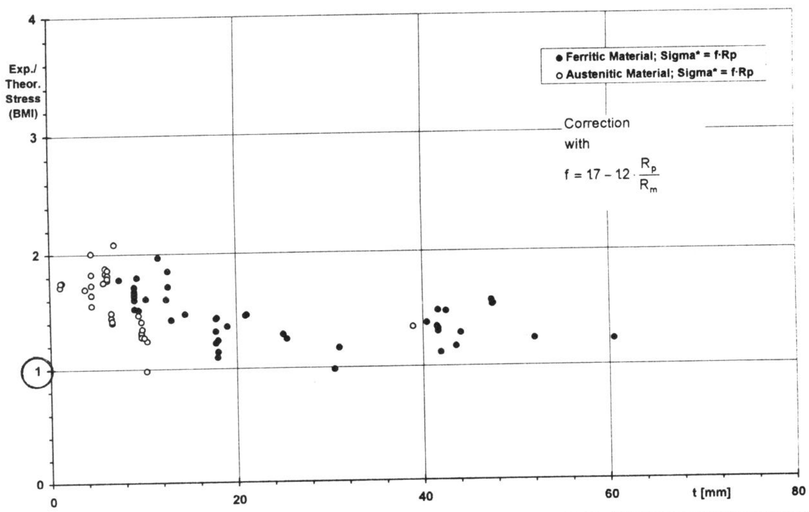
Circumferential Through-Wall Cracks: Flow Stress Concept (FSC)
Using Experiments with Av > 45 J and WM = BM

Figure 5



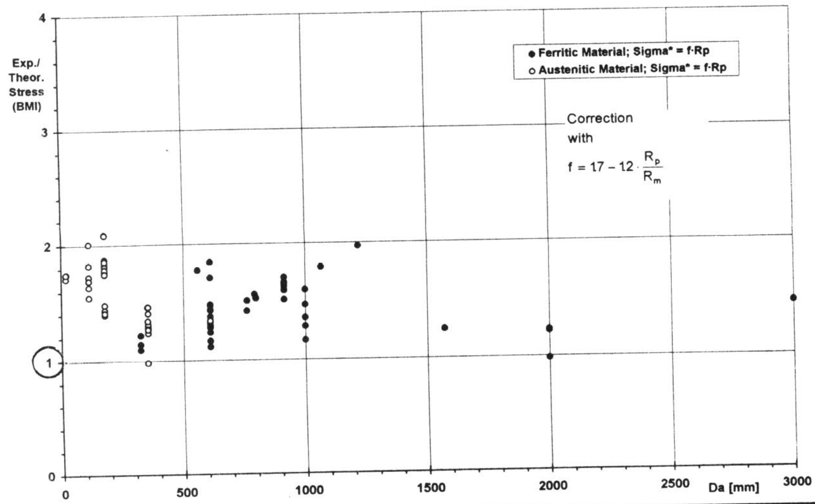
Axial Through-Wall Cracks: BMI-Formula with add. correction using Experiments with Av > 45 J

Figure 6



Axial Through-Wall Cracks: BMI-Formula with add. correction using Experiments with Av > 45 J

Figure 7



Axial Through-Wall Cracks: BMI-Formula with add. correction using Experiments with Av > 45 J

Figure 8