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FROM: I. Zatz

SUBJECT: Evaluation of Crack Growth in CF8M AB Shim Welds – Rev.1

REFERENCE: "77 K Fatigue Crack Growth rate of Modified CF8M Stainless Steel Castings" by Walsh, et. al.

SUMMARY: Using the crack growth data of welded specimens from the referenced paper and the finite element analyses results presented by Kevin Freudenberg for the AB shim welds (most recently dated 11/7/07), a calculation has been made estimating the maximum acceptable initial flaw size in ½-inch welds to be 3.2 mm.

DISCUSSION: The referenced paper identifies that the average Paris constants in welded compact tension crack growth specimens to be C = 3.1E-11 mm/cycle and n = 4.15. The tests were performed in accordance to ASTM standard E647. The fracture toughness of the weld material at 77K was not indicated in this paper or elsewhere in the literature.

When comparing the general trend of Stage II crack growth behavior between the base material and the welded material, the indication is that the welded material appears to take longer to reach Stage II, but once there, a crack will propagate more rapidly in the weld than in the base material. This conclusion is based solely on comparing Paris constants, where the welds generally have a lower value of 'C' (which is a measure of the initiation of Stage II crack growth), but a higher value of 'n' (Stage II crack propagation rate).

Without a value of fracture toughness, a critical crack size in the welds cannot be ascertained; however, the fracture toughness can be roughly estimated from the value of stress intensity observed at the end of Stage II crack growth from the ASTM E647 test. This gives a first order sense of whether the critical crack sizes in the welds are limiting. A fracture toughness value for the weld material at 77K of 65 $MPa(m)^{1/2}$ was obtained in this manner. Using a stress of 175 MPa (approximately 25 ksi) and appropriate geometric correction factors, the critical crack size (which indicates failure) is calculated to be 10 to 11 mm.

The Paris constants allow for a crack growth calculation in welds when an initial flaw size is assumed. Accordingly, a series of calculations were made that estimate the final flaw size in a weld when the cyclic load, number of cycles and initial flaw size are specified. Note that the crack growth rate in such a calculation is also dependent on the weld and crack geometry. The data represents a thru-edge crack in tension (per the compact tension specimen used in the E647 test). No other data or fatigue curves for welds were available for the potential variety of initial flaw geometries that may occur. Fortunately, the peak stresses observed in the Freudenberg calculations point to edge cracks in tension being the most likely scenario, so that is consistent with the test data.

The following formula was used for the crack growth calculation:

N = (1 / [C*m*(S(Pi**0.5))**n]) * [(1 / ai**m) – (1 / af**m)]

Where:

N = Number of cycles – for 4 times life, 500,000 was used
C, n = Paris constants
m = (n/2)-1
ai = initial flaw size
af = final flaw size
S = Cyclic stress – chosen to be 175 MPa (this is a conservative value based on the results of Kevin Freudenberg's analyses)

This calculation shows the following results:

When 'ai' equals	'af' equals
1.0 mm	1.2 mm
2.0 mm	3.5 mm
3.0 mm	8.9 mm
3.2 mm	11.2 mm (critical crack size – failure)

This result indicates that a thru-edge flaw in the weld will propagate to an unacceptably large size in 500,000 cycles if the initial thru flaw is greater than 3.0 mm (approximately 1/8-inch). This is confirmed by the estimated fracture toughness calculation based on a weld width of ½-inch (approximately 12 mm). This back-calculates to an initial flaw size of 3.2 mm. Naturally, other initial defects in welds will produce different results, but it should be noted that surface flaws have a tendency to propagate through, as well as across, a material, until it usually evolves into a through flaw of the type on which this calculation is based. Some additional life will naturally be achieved with a surface flaw as opposed to a through flaw, but how much is unknown without additional data. So, to be as conservative as possible, it is recommended that the thru-edge crack flaw propagation results, presented herein, be used. For welds smaller than ½-inch, the initial acceptable flaw size will be smaller and would need to be re-calculated since the initial flaw does not scale linearly with weld size.