Allowance for Welds in Elastic Fatigue Analysis - Elastic Follow up in Welded Structures -

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ABSTRACT

This document proposes a simple approach to the problem of the allowance for welds in fatigue rules.

1 INTRODUCTION

While remaining in the context of a classic elastic fatigue analysis, the behaviour of the welded structure can be different from that of an identical structure with no weld, in the following three respects :

. With respect to its geometry : in the case of an as welded structure and, thus, involving an intensification of local strains which may be of two types :

- either affecting the whole section (for example stiffening of a pipe by pressure or ovalization due to reinforcement),
- or appearing very locally in singularities (which may go as far as the geometrical singularities in the sense of RB 3261.13 of RCC-MR (reference /1/), and which can be reached by a detailed analysis of the finite element type.

. With respect to the difference in cyclic properties between parent material and weld which may result in a type of an elastic follow-up. This scattering has been widely reported in literature (for example, in references /2/ to /5/) for various 304 and 316 steel assemblies. Figure 1 shows the difference between the cyclic curves for parent materials (316 SPH) and the weld (16.8.2) at 550°, materials used for SOFA tests (in progress at CEA). The curves intersect at about 1.2 % strain. Below that value, the strain will be amplified in the parent material and above that value it will be amplified in the weld. A non-elastic calculation of the whole structure allowing for these differences in cyclic properties should allow the evaluation of the intensification, K, of the strains.

. With respect to its fatigue strength properties which may be different from those of the parent material, at least if we use the results on test specimens taken on moulds as a basis for the metal deposited (see figure 2).

The differences in properties must be taken into account in the evaluation of the fatigue damage.

In this paper we will only consider the second effect, i.e. elastic follow-up between parent metal and weld.

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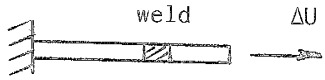
2 ANALYTICAL CALCULATION OF ELASTIC FOLLOW-UP

It is possible to evaluate coefficient K in simple cases and for the classification of conventional loads : membrane - bending and peak.

In each of these cases, factor K can be calculated simply on the shells by parametarizing the relative lengths of the parent material and of the weld, on condition that the cyclic curves of both materials are known at the correct temperature. The calculation is based on equilibrium, continuity and elastoplastic behaviour equations and concerns shells with "plane stress" hypothesis for cases 2.1 and 2.2 and with "plane strain" hypothesis for cases 2.3 and 2.4.

2.1 Membrane : Km

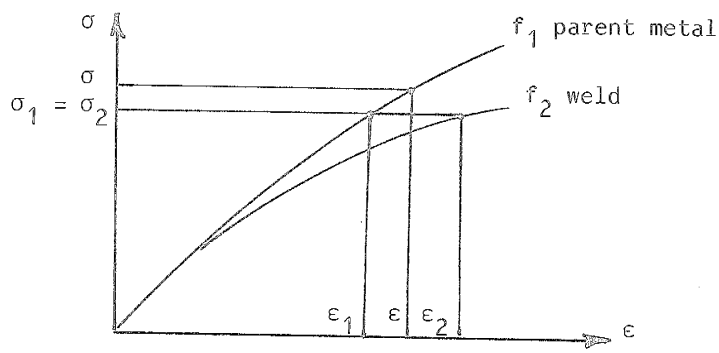


The comparison between a shell with a transverse weld subjected to a displacement Δu resulting in a membrane load and a shell with the same geometry with no weld, subjected to the same load allow Km to be determined.

ε_1 and ε_2 are strain respectively in parent metal and in weld in case of welded structure and ε is strain in case of no-welded structure.

The respective lengths of the parent material and the weld are l_1 and l_2 ($l_1 + l_2 = l$). The exact position of the weld has no effect on the result.

This allows us to illustrate the cyclic curves as follows :



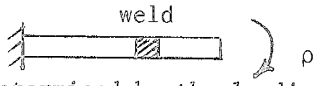
In the case of 316 SPH, welded by 16.8.2 at 550°, the characteristics of which are given with figure 1, the values of $\varepsilon_2/\varepsilon$ and $\varepsilon_1/\varepsilon$ with respect to ε paramaterized by l_2/l are applied to figures 3 and 4, respectively.

We note that :

- With cyclic curves that intersect at approximately 1.2 % :
  - the intensification of the stress is located in the welded section, Km = $\varepsilon_2/\varepsilon$ (figure 3) for the values of $\varepsilon > 1.2$ %,
  - the intensification of the stress is located in the parent material, Km = $\varepsilon_1/\varepsilon$ (figure 4) for $\varepsilon < 1.2$ %.
- For each value of ε, there is an asymptotic value of $\varepsilon_2/\varepsilon$ when the proportion of the weld respect to the length of the structure becomes very small.
- Km can be very great when the strains are great.
- For this type of load, it is thus possible, if we know the properties of both materials, to determine K once we know $\Delta\varepsilon$ for each cycle (calculated for a material with no weld) and the proportion of weld, l_2/l.

Indeed, it is reasonable to consider that the variation in the membrane strains will be limited. The problem is to find a likely value for this limit in order to judge the values of K obtained.

2.2 Bending K_F



In the same maner K_F can be determined by the loading of constant bending.

By imposing a curvature at the end point of two shells (with and without weld) :

ρ_1 and ρ_2 are curvature respectively in parent metal and in weld in case of welded structure and ρ is curvature in case of no-welded structure.

In the case of 316 SPH and 16.8.2, the values of $\rho_2/\rho = \varepsilon_2$ max/εmax and $\rho_1/\rho = \varepsilon_1$ max/εmax with respect to εmax = ρe/2 parameterized by l_2/l are given in figures 6 and 7, respectively.

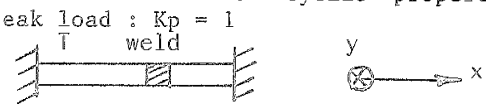
The same remarks can be made in the case of the membrane with lower intensification levels for a given ε.

Note : a calculation of the same type could be performed with a pipe in bending.

2.3 Peak : Kp

There is no redistribution of the strains between the 2 neighbouring sections of shell as the loading is self-balanced. There will, thus, be no elastic follow-up due to the difference of cyclic properties of the materials in the case of a peak load : Kp = 1

2.4 Thermal membrane K_T



In this case, membrane loading is two-dimensional.

Three hypothesis are made :

- there is no strain intensification in the direction parallel to the weld (y),
- the shell remains flat which means that the mechanical strains are equal to zero,
- the Poisson's ratio varies from 0.3 in elasticity to 0.5 in plasticity.

These three hypothesis were verified by the finite element calculations described in 3.

The results obtained are shown in figures 7 and 8, ε_1 and ε_2 are thermal stresses in the direction perpendicular to the weld (x).

For the same thermal strain along x on the same structure with no weld, we obtain $K_T > K_M$.

2.5 Thermal bending $K_{\Delta T}$

Bending loading is two-dimensional.

The same three hypothesis are made as for the last case. The finite element calculations described in 3 show that hypothesis 2 is not verified for certain geometries. In certain cases, the plate moves out of the plane and global strains appear, releasing the thermal strains.

Globally, K intensifications decrease.

The results obtained by this envelope calculation of actual cases are shown in figures 9 and 10, ρ_1 and ρ_2 are thermal curvatures in direction x.

For the same curvature : $K_{\Delta T} > K_F$.

3 FINITE ELEMENT CALCULATION OF ELASTIC FOLLOW-UP

These calculations were performed with the INCA code from CASTEM.

3.1 Unidimensional (membrane and bending)

The finite element calculations in plane stress and strain hypothesis give identical results to the analytical calculations (see 2.1 and 2.2).

3.2 Bidimensional plane cases (membrane and bending)

In the case of the thermal membrane (see 2.4), the results are identical to the analytical calculation and the three hypothesis for this calculation are verified.

On the other hand, in the case of thermal bending, the flatness hypothesis is not verified and the K_T values, which then depend on the position of the weld with respect to the edge, are always lower than those for the analytical calculation which can be considered as an envelope case.

3.3 Axisymmetrical cases

. The cases of unidimensional and bidimensional membrane and bending give lower K coefficients than the flat cases and this is explained by the following two observations :

- there is circumferential coupling (Poisson effect),

- the radial displacement of the weld with respect to the base material due to the effect already mentioned is propagated in the base material.

In all cases, it is noted that strain in the direction parallel to the weld is not intensified.

The analytical curves established for the flat cases are always envelopes for axisymmetrical cases.

. The case of a forced local displacement was studied.

Regardless of the position of the weld, the shell geometry and the decay parameter, K, is always very close to 1. This may be explained by the fact that the energy stored in the structure is much smaller than that for the loads previously dealt with for the same degree of local deformation.

4 CONCLUSIONS

For a known base-material/weld couple, it is possible, by takin a few simple envelopes, to determine the intensification of strains related to the heterogeneity of the behaviour laws, which can be used in fatigue analysis of the welded junctions.

This study is to be completed by more complex structural and load analysis. Analogous work is to be undertaken on the elastic follow-up due to the differences in creep properties.

Lastly and in parallel, tests are being carried out on a mockup of the plate/ring junction-type (SOFA).

The sensitivity of the results to the dispersion of behaviour laws should also be integrated into the dimensioning approach.

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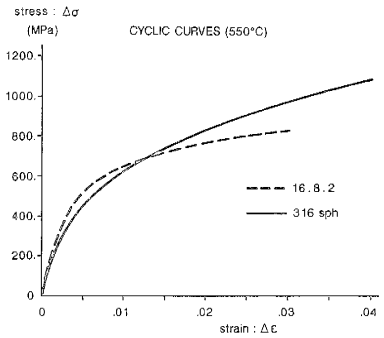


FIGURE 1

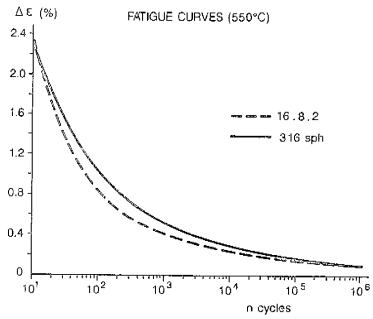
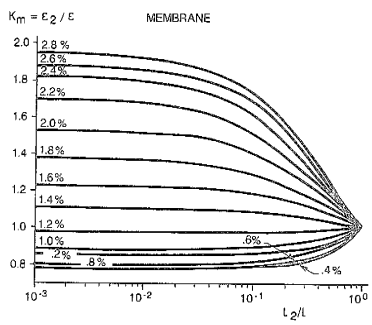


FIGURE 2



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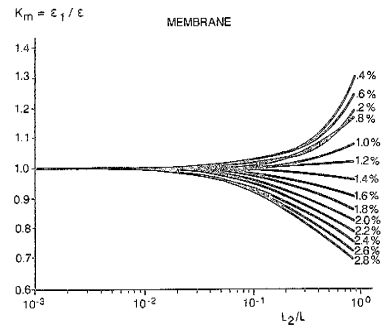

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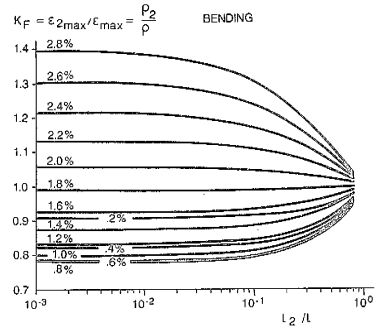

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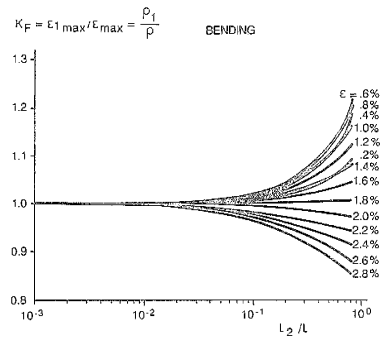

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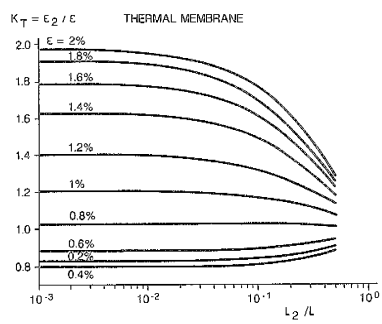

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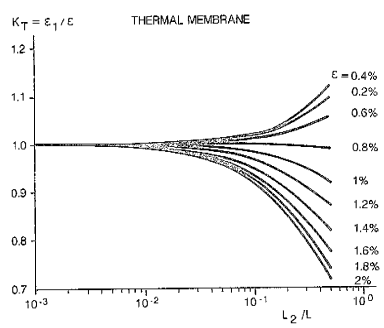
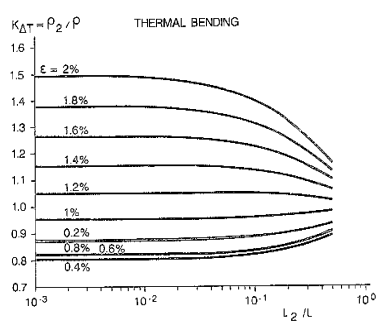


FIGURE 8



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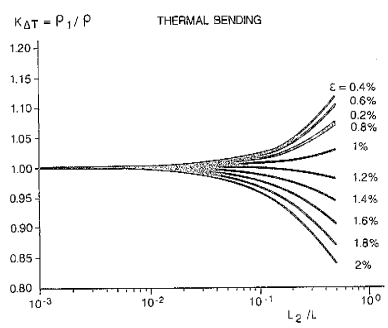

FIGURE 10