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Kostas is currently in the second year of his PhD at the University of Bristol and TWI. His research focuses on investigating the effect of load biaxiality on the integrity of cracked components and the current capabilities of Fitness for Service standards in addressing it. He is sponsored by the UK Engineering and Physical Sciences Research Council and TWI and conducts his research in both facilities (UOB, TWI). Prior to starting his PhD in July 2017, Kostas completed his diploma in Marine Engineering and Naval Architecture at the National Technical University of Athens. Kostas believes this research will contribute towards the more accurate assessment of components under complex loading and ensure safety of such components whilst saving time and reducing costs.

Effects of biaxiality on engineering critical assessments

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I. INTRODUCTION

Engineering components such as pressure vessels are usually subject to pressure, residual stresses generated from welds during manufacturing, and thermal stresses. Such complex loading often creates a multiaxial stress state. Surprisingly, the effects of load triaxiality is often ignored in standard assessments of integrity.

Substantive research has been conducted to address the effect of load biaxiality on integrity [1]. Load biaxiality increases the crack tip multi-axiality and thus increases plastic constraint, or in other words, it suppresses the flow of plasticity. It has been shown that there is a decrease in the critical value of the energy release rate (J_c) at fracture with increasing plastic constraint. This is a well-established effect of biaxiality on the lower shelf and in the transition region. However, many structures, such as pipelines carrying fluids at ambient temperature under a combination of internal pressure and axial load, experience biaxial loads on the upper shelf, where plastic collapse is the dominant failure mechanism. Experimental evidence showing biaxiality effects on plastic collapse [2] strongly suggest a correlation between variation in limit load/strain capacity/plasticity flow and load biaxiality. Thus, many researchers have studied the load bearing capability of cracked components under biaxial (or combinations of) loading [3].

The current advice on biaxiality in the R6 [4] and BS 7910 [5] FFS procedures is limited and emphasises the constraint effects on fracture toughness. This work focuses on quantifying the effect of biaxial loading on the integrity of cracked components as well as evaluating the precision with which R6 and BS 7910 assess such components.

II. APPROACH

To better understand and more accurately assess the effects of biaxial loading on the integrity of a component, biaxial and uniaxial tests conducted previously in TWI have been reanalysed. These large-scale tests were conducted on A533B pressure vessel steel plates [6] which had a cruciform specimen geometry, shown in Figure 1.

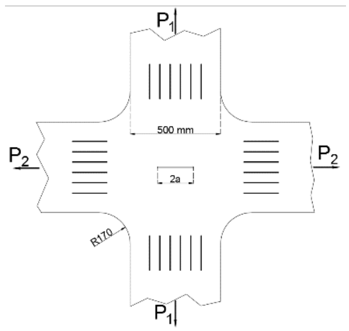

Figure 1 Biaxially loaded specimens

Two of these tests are assessed here, firstly with the use of an Option 1 assessment, and then with finite element analyses (FEA), employing Abaqus finite element code, for an Option 3 assessment. The two specimens (originally named #40 and #41 in [7]), were equibiaxially ($k=1$, i.e. $P_1=P_2$) and uniaxially ($k=0$, $P_2=0$) loaded respectively. The two specimens had similar flaw geometry (i.e. through thickness cracks, $2a$ = 200 mm) and were tested at similar temperatures ($T=-100^oC$), corresponding to the lower transition fracture toughness. A 2D finite element model with 2840 plane strain elements was created. Considering sample symmetry, only a quarter of the cruciform geometry was modelled as shown in Figure 2. Three analyses were run for each specimen: one to determine the limit load (global collapse) and another two to calculate J_{el}/J_{el-pl} to create the Failure Assessment Line (FAL).

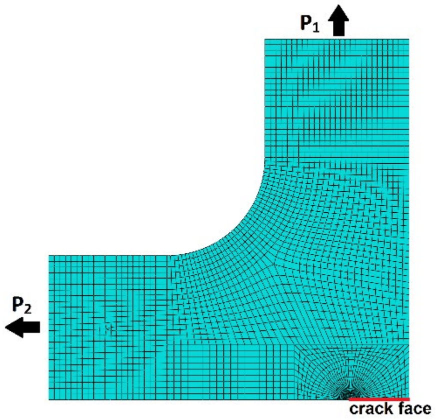

Figure 2 FE mesh of quarter of cruciform specimen subjected to biaxial loading

III. RESULTS

The failure assessment diagram is presented in Figure 3 which includes the basic BS 7910 Option 1 and the Option 3 assessments, derived from FEA. The Option 1 assessments, which use the handbook solutions of Annex P and Annex M, treat the specimens as flat plates under uniaxial loading with a through thickness crack.

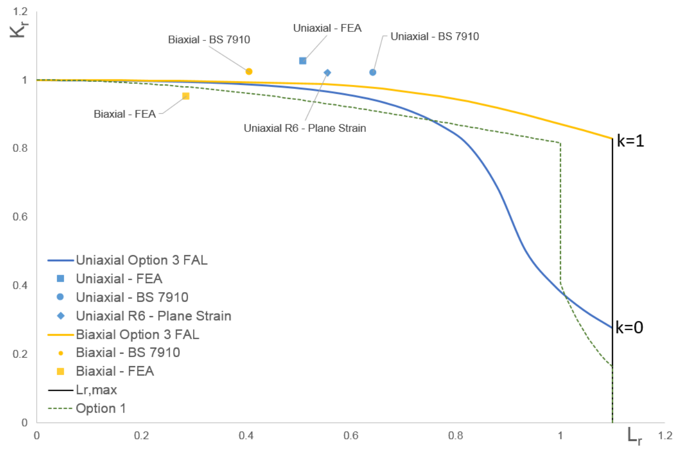

Figure 3 Results of Option 1 and Option 3 assessments

The results for the uniaxial specimen show that K_r values have been accurately predicted by both analytical and numerical solutions, while for L_r the R6 plane strain solution lies close to the FEA derived solution and the plane stress BS 7910 solution produces higher values of L_r. This is expected since the numerical modelling assumed plane strain conditions. The small deviation between the analytical and the numerical solution is expected due to the geometry of the specimen being different than that of a plate. For the biaxially loaded specimen, using the reference stress solutions for flat plates produces L_r values that are much higher than those derived from FEA. Additionally, the crack driving force calculated at the failure load is lower than that of the uniaxially loaded plate handbook solution, leading to lower values of K_r and the assessment point lying inside the safe zone of the FAD. It should be noted that specimen #40 also experienced an inhomogeneous temperature field around the crack, which was accounted for with a thermal stress of 110 MPa in a previous study [7] and was also included in the current analysis.

IV. DISCUSSION

It can be concluded that using the flat plate solutions of BS 7910 gives conservative results when assessing a biaxially loaded structure, i.e. generating an assessment point outside the safe zone. However, the results create a need for further exploration especially in the case of the biaxially loaded specimen whose point lies inside the safe zone of the FAD. The latest could be the result of the way in which the stress intensity factor was estimated from the thermal stress or the definition of the lower bound fracture toughness used to assess it. Additionally, the Option 3 failure assessment line of the uniaxial specimen has a smaller safe zone than that of Option 1, which contrasts with the high conservatism that the Option 1 FAL should ensure.

V. FUTURE PLAN

The current experimental database is being analysed further to obtain an explanation about the current peculiarities contained in the results.

An experimental programme is currently underway to capture the effect of load biaxiality throughout a spectrum of temperatures that vary in the transition region of the fracture toughness.

VI. ACKNOWLEDGEMENTS

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