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Damage and Void Shape Evolution during Destructive Testing of Resistance Spot Welded Joints

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ABSTRACT

Ductile plug failure of resistance spot welded test specimens is studied, using the recent extensions to the Gurson model accounting for non-spherical void growth or damage development during low triaxiality shearing. A comparison of the predicted mechanical response is presented when using either i) the Gurson-Tvergaard-Needleman (GTN) model [1, 2], ii) the shear extension to the GTN-model by Nahshon and Hutchinson [3] or iii) the Gologanu-Leblond-Devaux (GLD) model [4]. All models are here based on an elastic-viscoplastic constitutive relation and account for void nucleation, void growth and coalescence. Hence, the only damage parameter is the void volume fraction, f, while a void shape parameter, $W = R_1/R_2$, denoting the void aspect ratio, exists in the GLD-model. Here, R_1 and R_2 are the length of the first and second axes of the spheroidal voids, respectively. Thus, $W > 1$ corresponds to a prolate void, while $W < 1$ is an oblate void. The work to be presented is based on the studies in [5, 6, 7]. In [5], the GTN-model was used to reproduce experimental observations for the plug failure mode during shear-lab testing, while the change from plug failure to interfacial shear failure was modelled using a shear modified GTN-model in [6]. A study of the void shape evolution is presented in [7] together with a comparison of the above models.

All studies are carried out in full 3D, using a finite element (FE) implementation of the various damage models. The FE formulation is here based on a total Lagrangian framework of the field equations and implemented in a fully dynamic code, using 20 node solid elements for spatial discretization. The dynamic principle of virtual work is then evaluated by reduced Gaussian quadrature, while the time integration is performed by a standard explicit Newmark β-procedure. To limit numerical difficulties the element vanishing technique is applied as the yield surface shrinks to a point in stress space for increasing f.

As discussed in [5], ductile plug failure during shear-lab testing of single spot welded joints occurs as plastic straining localizes in the mid-section of the specimen near the heat affected zone (HAZ), which makes the spot weld rotate (see Figure 1a). Voids thereby nucleate and damage develops in this thin-region under moderate stress triaxiality and evolves along the circumference of the spot weld (see Figure 1b). Finally, a critical void volume fraction is reached and coalescence occurs, leading to loss of load carrying capacity. This plug failure mode is of a tensile nature and any effect from a shear modification should therefore be limited. However, as discussed in [6] the shear modification by Nahshon and Hutchinson needs some correction to be more realistic during plug failure and a simple extension has therefore been suggested. This simple extension is introduce as a ramping function on the shear-modification term suggested by Nahshon and Hutchinson, which reduces the model to that of Gurson-Tvergaard-Needleman at moderate to high stress triaxiality. The tensile nature

of the plug failure mode is clearly seen from the void shape evolution (see Figure 1c). Void nucleation is here assumed governed by fracture of particles in their equatorial plane (hence, $W_0 = 0.01$ is chosen). These very oblate voids are seen to evolve towards a spherical $(W = 1)$ or even prolate $(W > 1)$ shape in the region of localization, indicating significant stretching of the material.

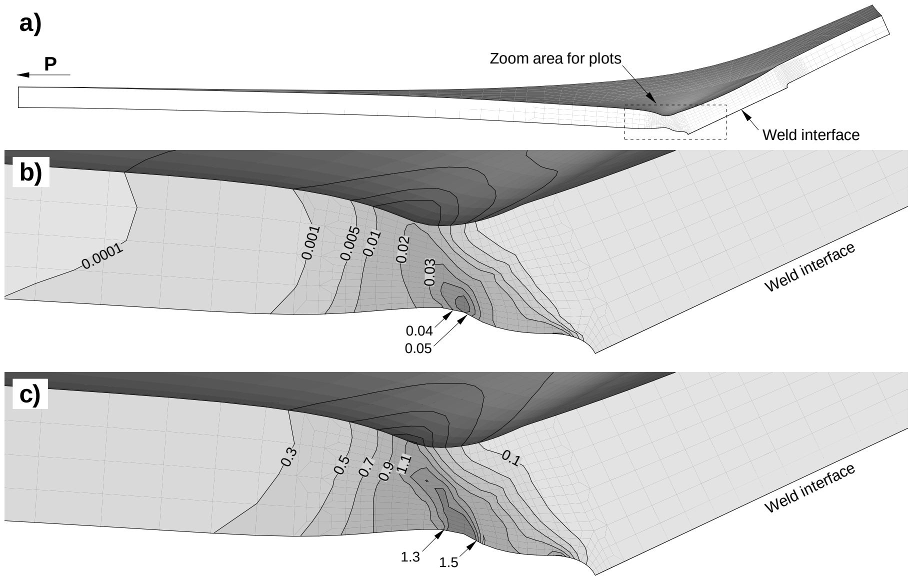

Figure 1: Plug failure of shear-lab specimen containing a single resistance spot weld, a) Deformed specimen geometry, and curves of constant b) void volume fraction, f, c) void aspect ratio, W.

With focus on destructive testing of resistance spot welded joints, a discussion of the intended and achieved effects from the various models will be presented. Damage development, void shape evolution and its influence on the load-displacement curves is here of special interest.

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