Cohesive properties at ductile tearing - Discussion of fracture paper #13

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In this review of particularly read worthy papers in EFM, I have selected a paper about the tearing of large ductile plates, namely:
”Cohesive zone modeling and calibration for mode I tearing of large ductile plates” by P.B. Woelke, M.D. Shields, J.W. Hutchinson, Engineering Fracture Mechanics, 147 (2015) 293-305.
The paper begins with a very nice review of the failure processes for plates with thicknesses from thick to thin, from plane strain fracture, via increasing amounts of strain localisation and failure along shear planes, to the thinnest foils that fail by pure strain localisation.
The plates in the title have in common that they contain a blunt notch and are subjected to monotonically increasing load. They are too thin to exclusively fracture and too thick to fail through pure plastic yielding. Instead the failure process is necking, followed by fracture along a worn-out slip plane in the necking region. Macroscopically it is mode I but on a microscale the final failure along a slip plane have the kinetics of mixed mode I and III and, I guess, also mode II.
A numerical solution of the problem resolving the details of the fracture process, should perhaps be conceivable but highly unpractical for engineering purposes. Instead, the necking region, which includes the strain localisation process and subsequent shear failure is a region of macroscopically unstable material and is modelled by a cohesive zone. The remaining plate is modelled as a power-law hardening continuum based on true stress and logarithmic strains.
The analysis is divided into two parts. First a cross-section perpendicular to the stretching of the cohesive zone is treated as a plane strain section. This is the cross section with a shape in which the parable with a neck becomes obvious. Here the relation between the contributions to the cohesive energy from strain localisation and from shear failure is obtained. A Gurson material model is used. Second, the structural scale model reveals the division of the tearing energy into the cohesive energy and the plastic dissipation outside the cohesive zone. The cohesive zone model accounts for a position dependent cohesive tearing energy and experimental results of B.C. Simonsen, R. Törnqvist, Marine Structures, vol. 17, pp. 1-27, 2004 are used to calibrate the cohesive energy.
It is found that the calibrated cohesive energy is low directly after initiation of crack growth, and later assumes a considerably higher steady

state value. The latter is attained when the crack has propagated a distance of a few plate thicknesses away from the initial crack tip position. Calculations are continued until the crack has transversed around a third of the plate width.

I can understand that the situation during the initial crack growth is complex, as remarked by the investigators. I guess they would also agree that it would be better if the lower initial cohesive energy could be correlated to a property of the mechanical state instead of position. As the situation is, the position dependence seems to be the correct choise until it is figured out what happens in a real necking region

I wonder if the investigators continued computing the cohesive energy until the crack completely transversed the plate. That would provide an opportunity to test hypothesises both at initiation of crack growth and at the completed breaking of the plate. The situations that have some similarities but are still different would put the consistency of any hypothesis regarding dependencies of mechanical state to the test.

I am here taking the liberty to suggest other characteristics that may vary with the distance to the original crack tip position.

The strains across the cohesive zone are supposed to be large compared to the strains along it. This is the motivation for doing the plane strain calculations of the necking process. Could it be different in the region close to the original blunt crack tip where the situation is closer to plane stress than plane strain? The question is of course, if that influences the cohesive energy a distance of several plate thicknesses ahead of the initial crack position.

Another hypothesis could be that the compressive residual stress along the crack surface that develops as the crack propagate, influence the mechanical behaviour ahead of the crack tip. For very short necking regions the stress may even reach the yield limit in a thin region along the crack surface. Possibly that can have an effect on the stresses and strains in the necking region that affects the failure processes.

My final candidate for a hypothesis is the rotation that is very large at the crack tip before initiation of crack growth. In a linear elastic model and a small strain theory, rotation becomes unbounded before crack growth is initiated. A similar phenomenon has been reported by Lau, Kinloch, Williams and coworkers. The observation is that the severe rotation of the material adjacent to a bi-material adhesive lead to erroneous calibration of the cohesive energy. Could this be related to the lower cohesion energy? I guess that would mean that the resolution is insufficient in the area around the original crack tip position.

Are there any other ideas, or, even better, does anyone already have the answer to why the cohesive energy is very small immediately after initiation of crack growth?

Per Ståhle