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An explicit FE-model of impact fracture in an adhesive joint

T. Carlberger [a,*], U. Stigh [b]

[a] SAAB Automobile AB, 46180 Trollhättan, Sweden
[b] University of Skövde, Sweden

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Abstract

Dynamic fracture of an adhesive layer in a structure is analysed. The structure represents some specific properties of an automotive structure and is simple enough to allow for closed form solutions obtained by the method of characteristics. These solutions are compared to results of explicit FE-analyses. The FE-solutions agree with the closed form solutions. Damage is included in the FE-model. Three constitutive models of the adhesive layer are used. It is shown that an amplification of the strain rate is achieved in the adhesive layer. It is also shown that an artificially increased flexibility of the adhesive in an aluminium structure gives only minor influences of the general behaviour. In some load cases, the adhesive layer will experience repeated loading/unloading. It is shown that in these cases an explicit FE-analysis with a "large" time step is more prone to give immediate rupture. Thus, the method is conservative.

Keywords: Adhesive joining; Dynamic fracture; Cohesive zone

1. Introduction

In the automotive industry increasing requirements on emissions, cost and crash performance is driving a technology change from mono-material spot welded steel to multi-material adhesively joined car bodies. Thus, the automotive industry is increasing its focus on the use of adhesive joints due to benefits in strength, stiffness and the capability of joining dissimilar materials. One reason adhesive joining has not reached general acceptance, is a lack of reliable and efficient simulation methods for adhesives in the field of crash simulation. In the present work, an attempt is made to demonstrate a useful technique for this purpose.

Most crash simulations are based on explicit FE-codes since these are capable of simulating fast events within a reasonable execution time. Explicit FE-codes do not require the solution of systems of equations as in implicit FE-codes. Instead, the equation of motion of each degree of freedom is solved individually, cf. e.g. [1]. This allows for very large models such as complete and detailed automotive structures, to be analysed for impact studies. Such a model typically consists of over one million degrees of freedom. The limit on

* Corresponding author. Tel.: +46 520 84 119; fax: +46 520 84 273.
E-mail address: thomas.carlberger@se.saab.com (T. Carlberger).

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Nomenclature

A	bar cross-sectional area
α	characteristic constant along characteristic line
β	characteristic constant along characteristic line
c	elastic wave speed
ε	strain
$\dot{\varepsilon}$	strain rate
E	Young's modulus
F	applied load
G	shear modulus
G_c	fracture energy/energy release rate
h	adhesive thickness
K	adhesive layer stiffness
k_a	cohesive zone stiffness
k	stiffness of bar
l_{min}	shortest distance between two nodes
L	element length, bar length
v	Poisson's ratio
ω	damage parameter
ω_{max}	largest eigenfrequency of the structure
ρ	material density
σ	peel stress
$\hat{\sigma}$	ultimate cohesive zone strength
τ	shear stress
τ_e, τ_c	characteristic time-parameters
T	time for the wave to travel the bar length L
t	time
Δt	time step
u	displacement
v	shear deformation
v	velocity of a material point
w	peel separation
x	coordinate direction

the degrees of freedom is due to limits in computer memory capacity and on the need to keep the solution time reasonable. To this end, the Courant limit (CFL-limit) is essential; in order to achieve numerical stability, the time step, Δt, must be smaller than $2/\omega_{max}$, where ω_{max} is the largest eigenfrequency of the structure. This is referred to as the "true critical time step" in the sequel. A useful estimate of the critical time step is given by the shortest time it takes an elastic wave to travel the distance between two nodes in the structure. This estimated critical time step, Δt_c, is given by

$$\Delta t_c = \frac{l_{min}}{c}, \tag{1a}$$

where

$$c = \sqrt{\frac{E}{\rho}}, \tag{1b}$$

where c is the wave speed, l_{min} is the shortest distance between two nodes, E is the Young's modulus and ρ is the density of the material. If the time step is chosen larger than Δt_c the FE-solution will fail due to numerical