Numerical assessment of strain rate in an adhesive layer throughout DCB and ENF tests

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Introduction

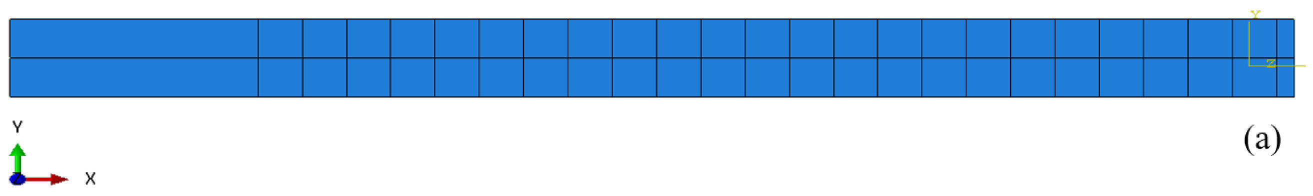
The increasingly larger use of adhesive joints in the automotive industry demands accurate adhesive characterization under dynamic loadings. Some authors have studied the effect of the strain rate on adhesive fracture toughness but without specifying the procedure used to calculate the strain rate [1]. Others simply assessed the effect of the test speed [2] and a few authors considered a nominal strain rate as defined by the test speed divided by the adhesive thickness [3].

In this work a numerical approach is proposed to assess the strain rate in mode I and mode II in DCB and ENF tests, respectively.

Methodology

Models for both DCB and ENF bonded with a structural adhesive, loaded at test speeds of 15 and 150 mm/s, were created in Abaqus/Explicit. Cohesive zone modeling, using traction separation, was used to simulate the adhesive layer.

Several partitions, represented in Figure 1 (a), were created along the upper and lower substrate, spaced 10 mm apart. Displacements were requested during the simulation at points located in these partition lines, both for the upper and lower substrates and this data was used to assess the strain rate along the adhesive bondline



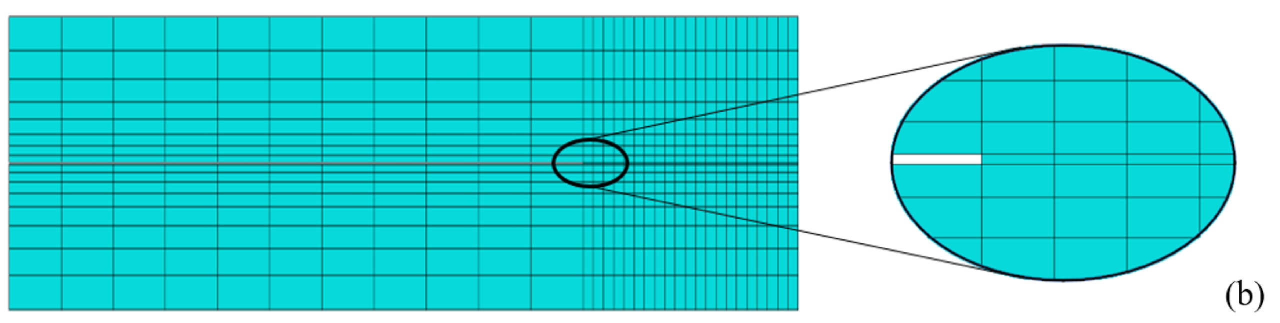


Figure 1 – Scheme of the partitions defined to require the displacements from Abaqus (a) and representative mesh used in the models (b).

The general definition of strain rate in a material being dynamically loaded is expressed in Equation 2

$$\dot{\varepsilon}(t) = \frac{d\varepsilon}{dt} = \frac{d}{dt}\left(\frac{L(t) - L_0}{dt}\right) = \frac{v(t)}{L_0} \qquad (1)$$

For DCB the formulation is as follows, since displacements in the direction of the crack propagation are negligible.

$$d_a = d_u - d_l \qquad (2)$$

$$\dot{\varepsilon}_{eng}(t) = \frac{v(t)}{L_0} \qquad (4)$$

$$v(t) = \frac{d_{at} - d_{at-1}}{t_t - t_{t-1}} \qquad (3)$$

$$\dot{\varepsilon}_{true}(t) = \frac{v(t)}{L_0 + d_{at}} \qquad (5)$$

Where d_u and d_l are the displacement of the upper and lower limit of the adhesive layer respectively, d_a is the relative displacement value, v is the opening velocity, L_0 is the adhesive thickness, t is the time, $\dot{\varepsilon}_{eng}$ and $\dot{\varepsilon}_{true}$ is the engineering and true strain rate, respectively. t and $t-1$ subscripts refers to the actual increment an the one just immediately before, respectively.

For each pair of nodes at a given distance from the loading pins a graph was plotted, registering strain rate data as a function of time, until the first increment in which failure in the adhesive occurs.

Equivalent procedure was created for ENF tests where displacements in both x and y direction were accounted for.

Results

Figure 2 and 3 presents the evolution of strain rate in the adhesive layers, using a DCB numerical model loaded at a displacement rate of 150 mm/s and a ENF numerical model loaded at a displacement rate of 15 mm/s, respectively.

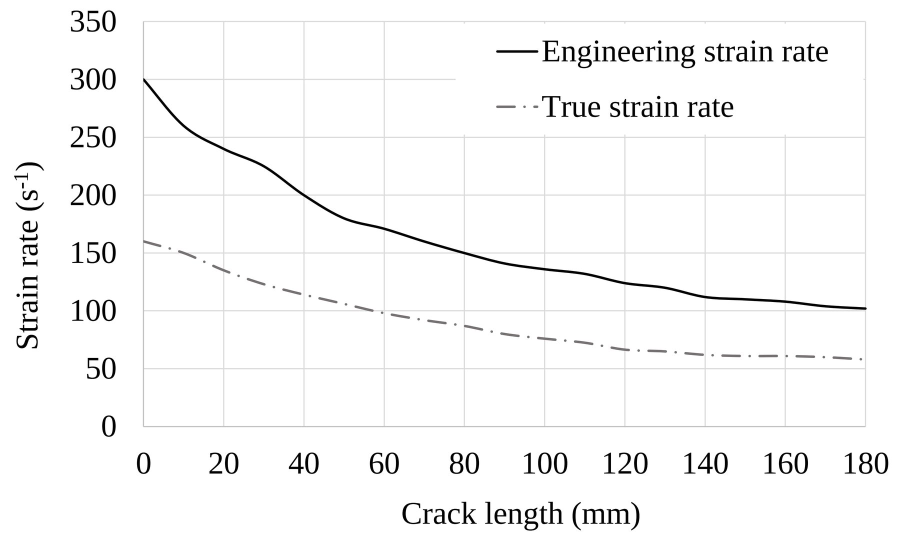


Figure 2 – Engineering and true strain rate along the crack length for DCB model of Adhesive A at 150 mm/s.

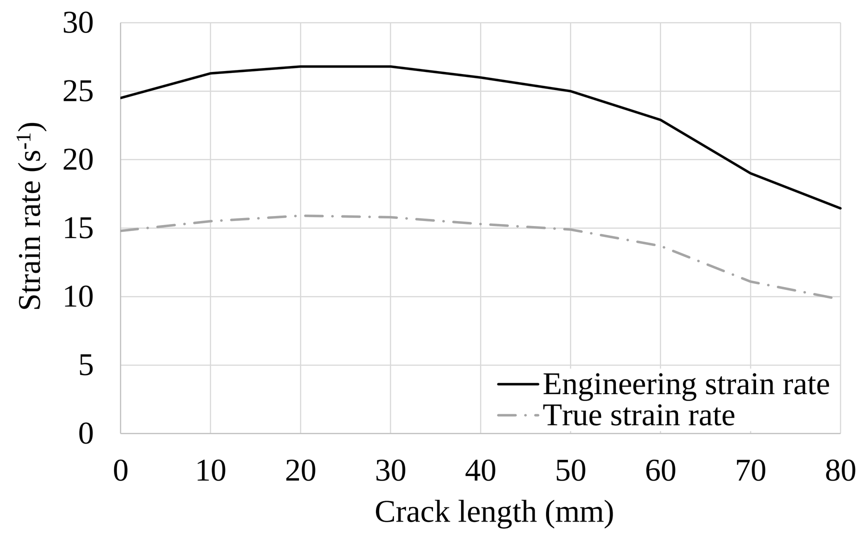
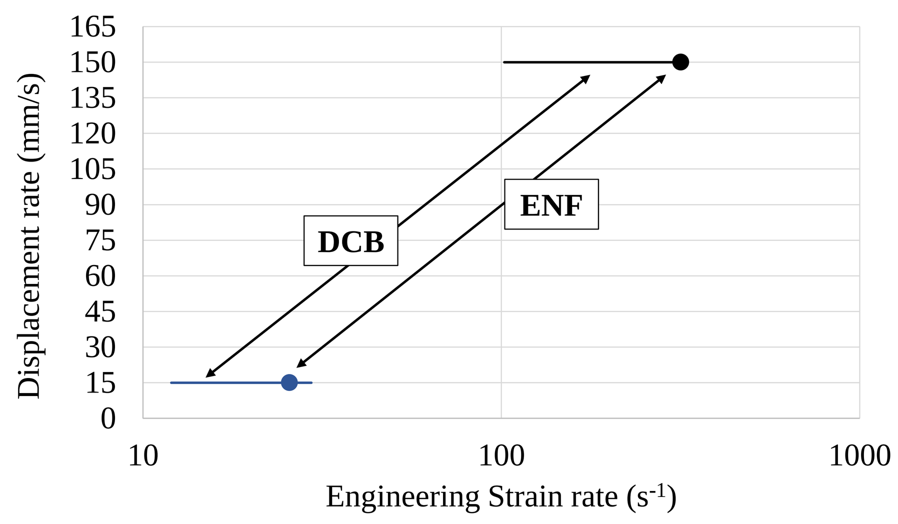


Figure 3 –Engineering and true strain rate along the crack length for ENF model of Adhesive A at15 mm/s.

In Figure 4 a compilation of the results of the strain rate as function of the crosshead displacement rate are shown, for both DCB and ENF models, loaded at 15 and 150 mm/s.



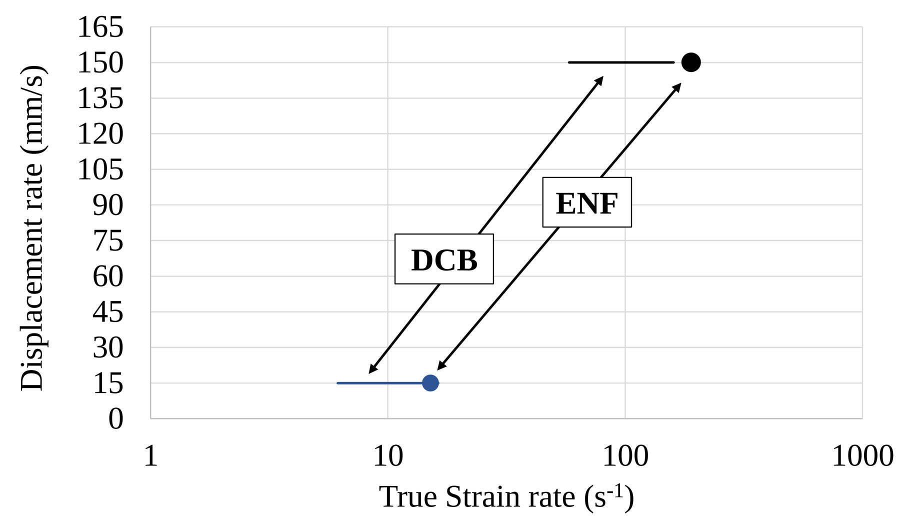


Figure 5 – Comparison of the strain rate between DCB and ENF for Adhesive A at 15 and 150 mm/s.

Conclusions

It was possible to conclude that for DCB tests, loaded at constant cross-head displacement rate, the strain rate along the bondline varies significantly, with the strain rate at the beginning of the test being three times higher than that at the end.

In the ENF test, a constant cross-head displacement rate results in a virtual constant strain rate for the initial 60 mm of crack length of the test, exhibiting noticeable variation only after this period. This period coincides with the time where the data provided by the test is useful to assess the G_{IIc}, making it reasonable to consider that, in practice, the strain rate is constant for ENF tests.

It is possible to conclude that, for the same crosshead displacement rate, in ENF tests, the adhesive is loaded at the higher end of the range of the strain rate values measured in the DCB models, both for the engineering and true strain rate.

References

[1] J. Bitner et al., "Viscoelastic fracture of structural adhesives," *The Journal of Adhesion*, vol. 13, no. 1, pp. 3-28, 1981.

[2] J. J. M. Machado et al., "Strain rate dependence of a crash resistant adhesive as a function of temperature for the automotive industry," *Proceedings of the Institution of Mechanical Engineers Part L-Journal of Materials-Design and Applications*, vol. 233, no. 11, pp. 2189-2203, Nov 2019.

[3] Z. Jia et al., "Effect of high loading rate and low temperature on mode I fracture toughness of ductile polyurethane adhesive," *Journal of Adhesion Science and Technology*, vol. 33, no. 1, pp. 79-92, 2019.

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