Engineering Fracture Mechanics 94 (2012) 85–86

Contents lists available at SciVerse ScienceDirect

Engineering Fracture Mechanics

journal homepage: www.elsevier.com/locate/engfracmech

Technical Note

Characteristic length of damage localization in steel

K.Y. Volokh

Faculty of Civil and Environmental Engineering, Technion – Israel Institute of Technology, Haifa 32000, Israel

ARTICLE INFO

Article history:
Received 13 December 2011
Received in revised form 16 April 2012
Accepted 7 July 2012

Keywords:
Characteristic length
Damage
Crack
Localization
Steel

ABSTRACT

In this note we calculate the characteristic length, ∼10 μm, of DH36 steel, which gives the size of a representative material volume where damage localizes initiating a crack. It is remarkable that our direct calculation does not require the knowledge of the internal structure of material and it is based on the results of the macroscopic experiments only.

1. Introduction

People used to think that cracks appear as a result of an ideal separation of two adjacent atomic layers. While such a scenario might be reasonable for nanostructures as graphene, carbon nanotubes, etc.; it is unreasonable for structural materials at the macroscopic scale. In the latter case the crack appears as a result of the massive breakage of atomic bonds. It is crucial to realize that the process of the bond breakage is not confined to two neighbor atomic planes. Just the opposite, the process involves thousands atomic planes within a representative characteristic *volume* of size h. It might be surprising at first glance but the crack surfaces created after fracture had had not be the closest neighbors inside the bulk before fracture.

Besides the purely scientific interest, the knowledge of the characteristic size of the damage localization, h, is crucial for numerical simulations of failure necessitated by engineering applications [1,2]. Indeed, the traditional failure simulations based on the approach of the classical local continuum mechanics are sensitive to the size of the geometrical mesh used for the spatial discretization. A way to suppress this pathological mesh-sensitivity is to enforce the characteristic length of the damage localization in the spatial discretization of material. For example, the characteristic length of the damage localization can set the size of the mesh in the case of the finite elements with the linear shape functions. The fixed size of the mesh is, thus, physically motivated and it should be used in the material areas where failure is supposed to localize in cracks and propagate.

2. Characteristic length for steel

The finding of the characteristic length is by no means trivial. It is usually attempted to extract this length from the consideration of the internal material structure at the microscopic level and then to fit it to the available results of the macroscopic experiments. For instance, a fairly sophisticated procedure for fitting the characteristic length of DH36 steel can be found in [3].

E-mail address: cvolokh@tx.technion.ac.il

0013-7944/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.engfracmech.2012.07.010

In the present note we show how to directly calculate the characteristic length for DH36 steel. The main idea behind the calculation is the following [4]. Let us assume that the characteristic linear size of the representative volume where bonds break during fracture is h. Then the work dissipated during the fracture process within the volume is $\sim\omega h^3$ where ω is the density of the *volumetric work of fracture*. It is important to emphasize that in the case of ductile fracture the work is *significantly* consumed by plastic deformations. Contrary to ductile fracture in the case of brittle fracture all work is consumed by the *elastically* breaking bonds. The latter is also the case of fracture in rubber [4].

On the other hand, the energy of the creation of two surfaces from the bulk is $\sim\gamma h^2$ where γ is the density of the *surface work of fracture* introduced by Griffith [5].

Equating two works, $\omega h^3 = \gamma h^2$, we get the characteristic length of the damage localization.

$$h = \frac{\gamma}{\omega}. \tag{1}$$

In the case of steel the Griffith theory developed for brittle fracture is not directly applicable because the plastic dissipation dominates and the *surface work of fracture* should be ductile [6].

$$\gamma \approx 10^3 \ [\mathrm{J/m^2}]. \tag{2}$$

In order to find the volumetric work of ductile fracture we will use the experimental data from [3, Fig. 3] which was obtained for the uniaxial tension including failure. The area under the engineering stress–strain curve equals the *volumetric work of fracture.*

$$\omega \approx 1.8 \times 10^8 [\mathrm{J/m^3}]. \tag{3}$$

Substituting (2) and (3) in (1) we get the characteristic length of the damage localization

$$h \approx 6 \times 10^{-6} [\mathrm{m}]. \tag{4}$$

3. Discussion

We calculated the characteristic length, $\sim$10 μm, of damage localization in DH36 steel. It is quite amazing that the experiments required for the calculation are macroscopic while characteristic length is an internal structural parameter of material. Thus, there was no need in a microscope to get insight into the characteristic material scale.

Two limitations of the calculation are evident. First, the used experimental data was obtained under quasi-static loads while during the dynamic crack propagation both values of the surface and volumetric fracture work can alter leading to the possible alteration of the characteristic length. Second, the value of the *volumetric work of fracture* was based on the data from the uniaxial tension tests while it can be different for the equal biaxial tension or other states of stresses and strains. We believe that despite the limitations the given value might be a good initial approximation for the characteristic length.

It should not be missed also that no specific constitutive model was called upon to support the calculation of the characteristic length and, thus, it can be used within theoretical frameworks varying from the local Gurson-type approaches to the nonlocal gradient- and integral-type theories.

We hope, finally, that the simple methodology proposed in the present note will encourage the experimentalists to estimate the surface and volumetric fracture energies for various steels under various loading conditions and, consequently, to provide the estimates for the characteristic lengths of the damage localization.

References

[1] Xia L, Shih CF. Ductile crack growth-I a numerical study using computational cells with microstructurally-based length scales. J Mech Phys Solids 1995;43:233–59.
[2] Gullerud AS, Xiaosheng G, Dodds RH, Haj-Ali R. Simulation of ductile crack growth using computational cells: numerical aspects. Engng Fract Mech 2000;66:65–92.
[3] Xue Z, Pontin MG, Zok FW, Hutchinson JW. Calibration procedure for a computational model of ductile fracture. Engng Fract Mech 2010;77:492–509.
[4] Volokh KY. Characteristic length of damage localization in rubber. Int J Fract 2011;168:113–6.
[5] Griffith AA. The phenomena of rupture and flow in solids. Philos Trans R Soc London 1921;A221:163–98.
[6] Wikipedia. Fracture Mechanics. <http://en.wikipedia.org/wiki/Fracture_mechanics>