Available online at www.sciencedirect.com

ScienceDirect

Procedia Structural Integrity 5 (2017) 302–309

Structural Integrity Procedia

www.elsevier.com/locate/procedia

2nd International Conference on Structural Integrity, ICSI 2017, 4-7 September 2017, Funchal, Madeira, Portugal

A Non-local Damage Model for Brittle Fracture in Metallic Structures with Stress Concentrators

Anastasiia Kostina*, Alena Terekhina, Oleg Plekhov

Institute of continuous media mechanics of the Ural branch of Russian academy of science, Ac.Koroleva st.,1, Perm, 614013, Russia

Abstract

This work is devoted to the development of the constitutive relations for the description of the defect evolution near the stress concentrators. A structural sensitive parameter is introduced as an averaging of the symmetrical tensor characterizing unit defect with the Boltzmann-Gibbs distribution function. Constitutive equation for structural parameter was derived under an assumption of the local thermodynamic equilibrium. The application of the developed approach is illustrated by the numerical simulation of a nonlocal fracture process occurring in a Grade-2 titanium specimen with a stress concentrator under uniaxial tension condition. Nonlocal character of the fracture near the stress concentrator was shown and physical explanation of the critical distance theory as a length of a dissipative structure growing in blow-up mode kinetics in the defect ensemble was proposed.

Peer-review under responsibility of the Scientific Committee of ICSI 2017

Keywords: mesoscopic defect; damage; critical distance theory; characteristic length; effective distance

1. Introduction

Evolution of the structural defects is observed on all scale levels during the deformation process of metals. Therefore, to develop phenomenological model for evolution of defects it is necessary to define physical level for microstructure description and introduce variable involving integral structural changes at lower scale levels. In order to describe strain localization and failure, the developed model should take into account initiation of new structural defects, their coalescence and growth.

* Corresponding author. Tel.: +73422378312; fax: +73422378487.
E-mail address: kostina@icmm.ru

2452-3216
Peer-review under responsibility of the Scientific Committee of ICSI 2017
10.1016/j.prostr.2017.07.175

Commonly, such models are derived within the framework of continuum damage mechanics. This approach is based on the introduction of a scalar or tensorial variable characterizing damage accumulation in the material. The damage development is described by kinetic equation linking damage rate with external variables. Kachanov (1958) in his pioneering work introduced scalar damage parameter as the reduction of the effective area due to the microdefects distributed within the specimen. Scalar damage variable characterizes the case of isotopic damage. Due to its relatively simplicity, this approach is widely used by many researches (Lemaitre (1985), Altenbach and Skrzypek (1999), Onat and Leckie (1988), Bammann and Aifantis (1989), Krajcinovic (1996), Voyiadjis and Park (1999), Chaboche (2008)). However, a single scalar variable is often insufficient to describe peculiarities of the considered processes. For instance, Othman et al. (1994) have used two independent scalar damage variables. One of them is responsible for softening due to the movement and interaction of dislocation and the other describes nucleation and growth of voids on the grain boundaries. Two damage variables for the description of tension and compression were used by Fremond and Nedjar (1995), Lee and Fenves (1998). Anisotropic damage description requires the use of the damage tensor of the second-, fourth- or eighth-order. Murakami (1988) defined the second-order damage tensor characterizing pore density in three principal planes. Desmorat et al. (2007) have shown that second-order tensorial damage variable is sufficient for the description of quasi-brittle material in case of monotonic loading. Anisotropic damage tensors of the fourth order defined in terms of the reduction of the elastic stiffness of the material were used by Ortiz (1985), Ju (1989). Damage tensors of the higher order are used by Chaboche (1993), Lubarda and Krajcinovic (1993), Cauvin and Testa (1999).

One of the possible ways to describe transition from damage accumulation to macroscopic fracture is introduction of characteristic length parameter. Such parameters can be introduced as structural (i.e. related to the grain size or the distance between defects), obtained from the proposed constitutive equations or can have a purely mechanical (macrosocpic) nature. The foundations of nonlocal strength theories had been laid by Neuber (1958) and Peterson (1959). The ideas proposed in these works have led to the development of the nonlocal models applied to the description of a fracture process (e.g., Belnoue et al. (2010), Mediavilla et al. (2006), Jirasek and Rolshoven (2003), Nguyen et al. (2015), Abu Al-Rub and Voyiadjis (2006), Peerlings et al. (2012)).

An attempt of generalization of various approaches to the fracture prediction has been made by Taylor (2008) and Susmel and Taylor (2008) in the framework of the critical distance theory. It has been shown that the critical distance theory can be successfully applied to the strength assessment of quasi-brittle and plastic materials under static, dynamic and cyclic loadings (Susmel (2006), Yin et al. (2014), Yin et al. (2015)). However, the physical meaning of the effective length parameter is still unclear.

This work is devoted to the theoretical justification of the critical distance theory on the base of statistical model of the evolution of defects proposed by Plekhov and Naimark (2009). We restrict ourselves to the case of quasi-brittle materials, so dislocation induced plasticity will be neglected. Damage accumulation is described by the second-order defect density tensor. Evolution equation for this internal variable is derived under the local equilibrium assumption. Damage evolution is characterized by initiation of dissipative structures in defect ensemble growing in blow-up regime. The spatial scale of the defect localization is considered as the effective length used in the critical distance theory. In order to verify the proposed theory the numerical simulation of the static loading of the Grade 2 titanium specimen was carried out. It has been shown that spatial scale of localization of the defect structure coincides with the critical distance for the considered material.

2. Mathematical model of damage to fracture transition in quasi-brittle materials

Description of the mesodefect ensembles requires definition of the parameters characterizing them and having a meaning of the independent state variables. In this work such variable is introduced in terms of the dislocation theory (Naimark O.B. (2003)). It is assumed that there are two types of defects – microcracks and microshears. Microcracks (microshears) modelling in terms of the dislocation theory has physical justification since initiation and evolution of these defects are accompanied by plastic deformation processes due to the dislocation movement. Symmetrical second-order tensor $\mathbf{s}$ characterizing unit defect has the following form in case of microcrcak:

$$\mathbf{s} = S\mathbf{nn} , \tag{1}$$