Available online at www.sciencedirect.com

ScienceDirect

Procedia Structural Integrity 2 (2016) 342–349

Structural Integrity Procedia

www.elsevier.com/locate/procedia

21st European Conference on Fracture, ECF21, 20-24 June 2016, Catania, Italy

More singular? Self-similar dynamics of damage localization and instability in dynamic fracture

Oleg B. Naimark

[a]ICMM UB RAS, Academika Koroleva st.,1, Perm 614013, Russia

Abstract

Dynamic fracture instability is studied for three characteristic statements: dynamic crack propagation, dynamic fragmentation and failure wave initiation to combine theoretical interpretation and "in-situ" high resolution experimental data for dynamically loaded quasi-brittle materials (PMMA, glasses, ceramics and fused quartz). Specific type of criticality (the structural-scaling transitions) was established in solid with defects in terms of two structural variables: defect density tensor (defect induced strain) and structural scaling parameter. Two critical values for structural scaling parameter were found that separate characteristic nonlinearity of free energy release in damage kinetic equation that allowed one to establish specific self-similar solution (blow-up dissipative structures) responsible for final stage of damage localization and crack initiation. The set of spatial scales of damage localization (that has the image of mirror zones) and corresponding "incubation" time follow from the self-similar solution as the "eigen-values" of non-linear problem. Different scenario of instability of dynamic fracture in mentioned experiments were analyzed as nonlinear dynamic problem in the presence of two self-similar solutions (two attractors): intermediate asymptotical solution for stress field in crack process zone (as the basement for stress intensity factor) and the set of blow-up self-similar solutions for damage localization kinetics playing the role of collective modes of damage localization. Theoretically predicted flicker noise temporal-spatial statistics was found in dynamic experiments for fused quartz and ceramic rod fragmentation combined with fracto-luminescence recording and analysis of fragment statistics. Resonance excitation of blow-up modes allowed explanation of self-similar pattern of multiple spall kinetics ("dynamic branch" under spall) due to "resonance" excitation of blow-up damage localization kinetics.

Keywords: Damage localization, blow-up self-similar solution, dynamic crack propagation, failure wave, fragmentation statistics

Corresponding author. Tel.: +7-342-2378-312.
E-mail address: naimark@icmm.ru

10.1016/j.prostr.2016.06.044

1. Introduction

Statistically based approach was developed for the constitutive modeling of materials to provide links between defect induced mechanisms of structural relaxation, damage-failure transition and material responses in wide range of load intensities. It is shown that the process of damage-failure transition can be considered as specific type of criticality in out-of-equilibrium system "solid with defects" and wide range constitutive model was proposed as the generalization of the Ginzburg-Landau approach in terms of independent field variables describing typical mesoscopic defects (microshears, microcracks). Specific types of the collective modes of defects were established as self-similar solution of evolution equation for mentioned damage parameter. This solution represents the intermediate asymptotical solution of damage evolution equation and describes the blow-up damage localization kinetics on the set of spatial scales (damage localization areas). The set of blow-up self-similar collective modes of defects can be considered as the independent variables provided universality of nonlinear dynamics of damage-failure transition from steady-state crack propagation to the branching regime with pronounced intermittency in crack propagation velocity, "resonance" excitation of damage localization in shocked materials ("dynamic branch" under spall failure, failure waves), spatial-temporal power law universality in dynamic fragmentation. Original experimental data supported the assumption concerning the role of multiscale blow-up collective modes of defects on self-similar responses of materials in wide range of load intensity

The goal of present study is to link the scenario of damage-failure transition in wide range of load intensity ith self-similar dynamics of damage localization supported by original in-situ experiments.

Nomenclatures mentioned in the article are listed below.

Nomenclature

F	free energy
$A,B,C,D,$ G, m	material parameters
δ	structural-scaling parameter
δ_*, δ_c	critical values of structural-scaling parameter
p_{ik}	defect density tensor
σ_{zz}	stress component
χ	nonlocality coefficient
Γ_p, Γ_δ	kinetic coefficients
ε	strain component
t	time
$\hat{C}$	elastic compliance tensor
$g(t)$	temporal function of blow-up self-similar solution
$f(\xi)$	spatial function of blow-up self-similar solution
τ_c	blow-up time
p_c	critical defect density
L_H, L_c	self-similar scales of damage localization
f	frequency
V	crack velocity
V_B, V_C	characteristic crack velocity
V_{fw}	velocity of failure wave

2. Structural-scaling transitions. Collective modes of defects

Statistical theory of typical mesoscopic defects (microcracks, microshears) allowed us to establish specific type of critical phenomena in solid with defects – structural-scaling transitions and to propose the phenomenology of damage-failure transition (Naimark (2004)). The key results of the statistical theory and statistically based