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Numerical simulation of dynamic fracture of concrete through uniaxial tension and L-specimen

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ABSTRACT

Dynamic fracture of concrete is numerically evaluated using uniaxial tension and L-specimen. Previous work by authors demonstrated interesting aspects such as crack branching beyond threshold crack speed. Uniaxial tensile behaviour of concrete under dynamic loads is difficult to study even numerically due to local problems near loading points. A specimen is designed to numerically assess the dynamic tensile behaviour that seems to be practical enough for carrying out experimental studies as well. The results demonstrate various phenomena such as crack branching, intercepting and re-branching. Dynamic behaviour of L-specimen shows that the direction of crack propagation strongly depends on displacement rate.

1. Introduction

Uniaxial tensile behaviour of concrete invariably dominates the behaviour of concrete specimens as well as structural elements. Therefore, in order to understand the dynamic fracture of concrete, it is essential to understand the dynamic fracture of concrete under uniaxial tension. However, to experimentally study the uniaxial tensile behaviour of concrete is difficult even under static loads, and therefore indirect methods such as Brazilian tests and compact tension tests are often employed. Even numerically, it is difficult to evaluate the direct dynamic uniaxial tensile behaviour of concrete since, at high loading rates, the failure always occurs locally, near the loading points. Therefore, under dynamic loads, the problem is studied through indirect tests such as split Hopkinson bar tests [2–11], with the underlying concept of the experiment involved in a compression wave from the impact that travels along the specimen and gets reflected at the end of the specimen as a tension wave. However, so far the tests have been mostly oriented to study certain parameters such as tensile strength as a function of loading rate instead of studying the complete fracture behaviour. Fig. 1 shows the results obtained by various researchers on the effect of loading rate on tensile strength of concrete as summarized by Malvar and Ross [12].

L-specimen poses a very interesting problem from the point of view of crack propagation and fracture of concrete and is often used to demonstrate the capabilities of material models as well as the phenomenon of mesh sensitivity [13,14]. This is a relatively simple test setup but to the knowledge of authors, there has been no experimental or numerical study to assess the dynamic behaviour of the specimen.

In this work, numerical investigations are carried out on a uniaxial tension specimen and an L-specimen as tested, for quasi-static loading conditions, by Winkler et al. [13] subjected to high rate loading. The analysis is carried out using the 3D FE code MASA based on the microplane model with relaxed kinematic constraint [15], developed at Institute for

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Nomenclature

c_0, c_2 material rate constants, calibrated by fitting test data
C_1, C_2 constants determined from experiments
C_R constant depending on poisson's ratio
D fracture energy
E effective Young's modulus of bulk material
E_0 initial energy at time t_0
f_c cylinder compressive strength of concrete
f_d dynamic strength
f_s static strength under monotonic load
f_t uniaxial tensile strength of concrete
G_c shear modulus
G_F fracture energy
k_i and m_i directions of shear microplane components
n_i normal vector components
S surface of the unit radius sphere
s_{cr} spacing of the parallel cracks
T kinetic energy
V deformation energy
v_R Rayleigh wave speed
W external work
$\dot{w}$ crack opening ratio
α parameter dependent on load and type of material and the way of loading
δ_{ij} Kronecker delta
ε average macroscopic strain normal to the direction of parallel cracks
$\dot{\varepsilon}$ strain rate
ε_{ij} macroscopic strain tensor
$\dot{\varepsilon}_{ij}$ components of the macroscopic strain rate tensor (indicial notation)
ρ_c specific weight of the material
σ stress at dynamic load
σ^0 stress at static load
$\dot{\sigma}$ stress rate under dynamic load
$\dot{\sigma}^0$ stress rate under static load
σ_D, ε_D deviatoric stress, strain components of the normal stress on microplane
σ_K, σ_M, ε_K, ε_M two shear stress–strain components on microplane
σ_N, ε_N normal stress, strain components on microplane
σ_V, ε_V volumetric stress, strain components of the normal stress on microplane

Construction Materials, University of Stuttgart. Rate sensitive microplane model has been employed as the material model, while the effect of inertia is accounted for by explicit dynamic analysis. It has been shown [1,16,18–20] that the rate sensitive

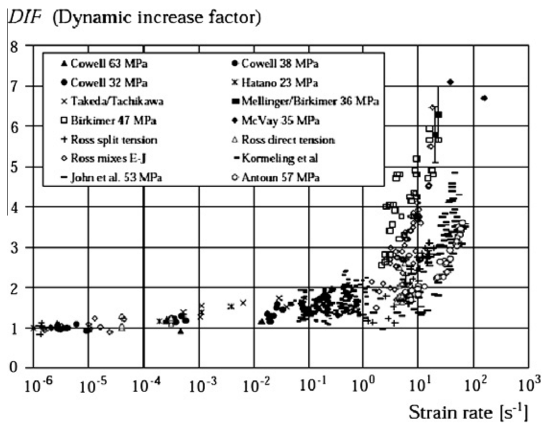

Fig. 1. Strain-rate dependence for concrete in tension, based on Malvar and Ross.