8th. World Congress on Computational Mechanics (WCCM8)
5th European Congress on Computational Methods in Applied Sciences and Engineeering (ECCOMAS 2008)
June 30 –July 5, 2008
Venice, Italy

MODELLING OF RATE EFFECTS AT MULTIPLE SCALES

R.R. Pedersen, A. Simone and L.J. Sluys

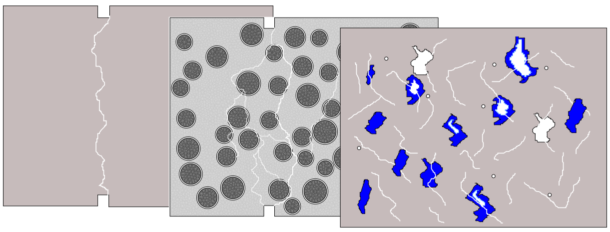
Delft University of Technology
Faculty of Civil Engineering and Geosciences
P.O. Box 5048, 2600 GA Delft, the Netherlands
r.r.pedersen@tudelft.nl

Key Words: *Impact, rate-dependency, multiple scales, visco-elasticity, visco-plasticity, damage.*

ABSTRACT

Two distinct physical mechanisms can be directly linked to the rate-dependent material properties in heterogeneous materials. For intermediate loading rates the strength increase is assumed to be related to the moisture effect in micro and nano pores [1], whereas the strengthening effect at higher loading rates is mainly caused by a change of failure mechanisms and by the effect of micro/meso-inertia [2]. Therefore, the characteristic length and time scales of heterogeneous materials depend on the scale of observation, the nature of the applied load and the loading rate.

We present a multiple-scale framework to describe the above rate-dependent mechanisms. An attempt is made to analyse the impact problem at three scales sketched in Figure 1. We have (i) a macro-scale at which the material is considered homogeneous, (ii) a meso-scale at which aggregates, matrix and interface between aggregates and matrix are explicitly modelled and (iii) a micro-scale model, where the rate effect induced by moisture (the so-called Stefan effect) is included through a semi-analytical model [3].



(a) (b) (c)

Figure 1: Sketch of different observation scales. A crack may be reproduced with a macroscopic continuum model (a), a mesoscopic model including aggregates and initial defects (b), and by a microscopic model of the cement matrix representing the Stefan effect (c).

At the macro- and meso-scales a rate dependent constitutive model [4] is used in which visco-elasticity is coupled to visco-plasticity and damage. Figure 2 shows a rheological representation of the model, where η_1^s and E_1 are the viscosity and stiffness related to the visco-elastic Kelvin element. In the visco-plastic model η_2^s is the viscosity and f_{tv} is the tensile strength. The hardening force q is dependent on the equivalent plastic strain κ to represent the softening behaviour. Furthermore, q is a function of the equivalent visco-elastic strain χ and strain rate $\dot{\chi}$ to account for the viscous hardening effect associated to the Stefan effect. The equivalent plastic strain also controls the evolution of the damage parameter ω, which affects the initial elastic stiffness E_2. A viscous length scale effect is introduced to control the

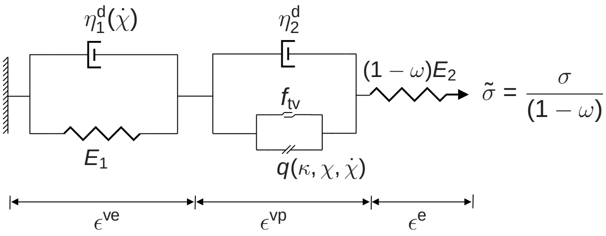


Figure 2: One-dimensional rheological model for the visco-elastic visco-plastic damage model, where ϵ^{e}, ϵ^{ve} and ϵ^{vp} are the elastic, visco-elastic and visco-plastic strains, respectively.

size of the fracture process zone. By comparison of the widths of the fracture process zone, the length scale in the meso-model and the macro-model can be coupled. In this fashion, a bridging of length scales can be established. A computational analysis of a Split Hopkinson bar test at medium and high impact load is carried out at macro-scale and meso-scale including information from the micro-scale.

REFERENCES

[1] P. Rossi , J.G.M. van Mier, F. Toutlemonde and C. Boulay. “Effect of loading rate on the strength of concrete subjected to uniaxial tension”. *Materials and Structures/Materiaux et Constructions*, Vol. **27**, 260–264, 1994.

[2] A. Brara, F. Camborde, J. Klepaczko and C. Mariotti. “Experimental and numerical study of concrete at high strain rates in tension”. *Mechanics of materials*, Vol. **33**, 33–45, 2001.

[3] A.V. Nguyen. “Historical Note on the Stefan Reynolds Equations”. *Journal of Colloid and Interface Science*, Vol. **234**, 195, 2000.

[4] R.R. Pedersen, A. Simone and L.J.Sluys. “An analysis of dynamic fracture in concrete with a continuum visco-elastic visco-plastic damage model”. *Engineering Fracture Mechanics*, submitted.