COST 526

"Automatic Process Optimization in Materials Technology"

(APOMAT)

Half-Yearly Report

1. Reporting Period	**1.1.2003 – 30.6.2003**
Project title	Formulation of Objective Function for estimating Fatigue Damage of Cold Forging Tool Steels at Micro Scale
Project leader Organization	**Dr. Tomaž Rodič** Faculty of Natural Sciences and Technology, University of Ljubljana, Slovenia.
Main collaborators involved	C3M

2. Funding Situation	
Amount of money received specifically for COST	2.9 kEuros
Other resources partially used for the project	0 kEuros

3. International Collaboration
(mention group and type of work done in collaboration during the reporting period)

Participation in the Working Group Meeting in Brussels + project progress report

X YES

❐ NO

LMT-ENS Cachan (France) – Micromechanical modelling of materials

4. Industry participation
(mention name of companies and work done in collaboration during the whole project)

Iskra-Avtoelektrika. Investigations of parameters influencing service life of tooling systems

5. Meetings, visits, exchange of scientists, short-term scientific missions	**Location, date**
Working Group Meeting Meetings with Iskra-Avtoelektrika	Brussels, May 2003 Ljubljana, Nova Gorica, 30.7.2003

6. Progress within the reporting period
(Not exceeding 3 pages, including tables and figures)

The work is being performed in conjunction with Ph.D. research work of Damijan Markovic who has developed a formulation for coupled macro-micro analysis of tooling systems for cold forging applications.

In this approach we consider the problems of heterogeneous structures, where the scales are not separated enough to be treated by the standard analytical homogenization procedures. They are strongly coupled and both modeled by the finite element method (FEM). Namely, a 'macro' finite element is at the same time the 'micro' window, where a lower level FE model on the 'micro' scale is used to get the 'macro' response (see Figure 1).

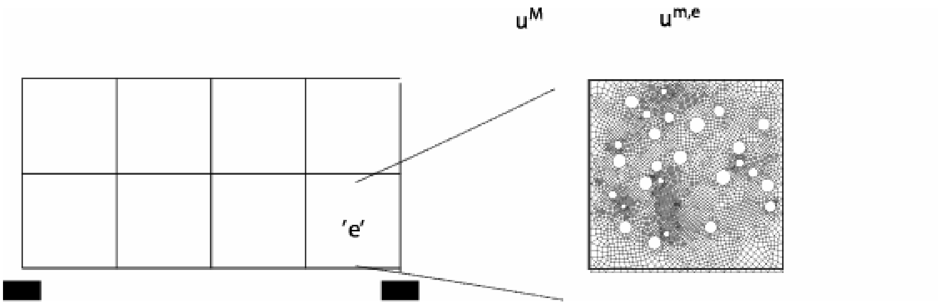

Figure 1: A two-scale model of the heterogeneous structure. Both scales, 'macro' scale on the left and the 'micro' scale on the right are modeled by the FEM.

The scale coupling is elaborated by using the localized Lagrange multiplier variational formulation, resulting in the stationary problem of the following potential:

$$\Pi = \Pi_{micro} + \Pi_{interface} + \Pi_{external} ,$$

where $\Pi_{external}$ is the loading term,

$$\Pi_{external} = -\int_V f u^m dV - \int_{\partial V} \bar{t} u^M dS ,$$

Π_{micro} is the free energy on the 'micro' level,

$$\Pi_{micro} = \int_V \Psi(\varepsilon^m, \xi^m{}_{\text{int}}) dV ,$$

and $\Pi_{interface}$ is the coupling term,

$$\Pi_{interface} = \int_{\partial V} \lambda (u^M - u^m) dS .$$

u^M and u^m are the 'macro' and 'micro' displacement fields, f is the force density, t the tractions imposed on the boundary, Ψ the 'micro' free energy density, ε^m is the 'micro' strain, $\xi^m{}_{int}$ are the 'micro' internal variables and λ is the Lagrange multiplier field. Imposing the stationarity condition $\delta\Pi = 0$, we get the set of equation for the weak formulation:

'micro' equilibrium

$$\int_V \delta\varepsilon : \sigma dV - \int_V \delta u^m f - \int_{\partial V} \delta u^m \lambda dS = 0 ,$$

'micro-macro' displacement compatibility

$$\int_{\partial V} \delta\lambda (u^M - u^m) dS = 0$$

and 'macro' equilibrium

$$\int_{\partial V} \delta u^M (\lambda + \bar{t}) dS = 0 .$$

We test then the approach for two different cases of Lagrange multiplier discretization, corresponding effectively to the displacement based and force-based interface. In the displacement based interface the displacements on the 'micro' boundary are supposed to have a linear distribution and in the case of the force based interface the boundary tractions are supposed to have a linear distribution.

We have shown in the articles cited below, that the choice of using one or the other type of the interface should depend on our ‘macro’ structural loading, the size of the ‘micro’ scale window and the quantities we need from the analysis.

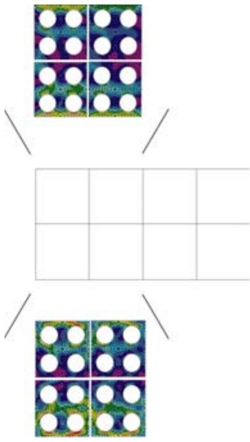

Figure 2: A simple example showing the difference (deviatoric stresses) between displacement based (bottom) and force based (top) interface. The material is the example is a porous metal with elasto-plastic matrix.

7. List of publications

a) Published

A.Ibrahimbegovic, D. Markovic : Strong coupling methods in multiphase and multiscale modeling of inelastic behavior of heterogeneous structures, *Comput.Meth.Appl.Mech.Engng*., 192:3089-3107,2003

A. Ibrahimbegovic, D. Markovic, F. Gatuingt: Constitutive model of coupled damage-plasticity and its finite element implementation, Revue Europeene des Elements Finis, 12/4:381-405,2003