MODELING OF THERMO-DAMAGE COUPLING IN ANISOTROPICALLY DAMAGED MATERIALS

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Material damage due to the development of microscopic cavities has marked effects not only on the mechanical but also on the thermal properties of materials. Thermal conductivity of damaged materials, in particular, is usually decreased due to damage, and often induces significant change of temperature fields.

The present paper is concerned with the modeling of heat transfer in anisotropically damaged materials and with its application to coupled thermal, mechanical and damage problems.

By representing the state of anisotropic damage by means of a second rank symmetric damage tensor

$$\boldsymbol{D} = \sum_{i=1}^{3} D_{ij} \boldsymbol{n}_i \otimes \boldsymbol{n}_j \,, \tag{1}$$

a current damaged configuration $\mathrm{B_t}$ and the corresponding fictitious undamaged configuration $\mathrm{B_f}$ of a Representative Volume Element (RVE) of the damaged material are first postulated. D_{ij} and $\boldsymbol{n}_i$ in equation (1) are the component of the damage tensor $\boldsymbol{D}$ and a base vector of a Cartesian coordinate system.

Then, by taking account of the effective undamaged surface element of $\mathrm{B_f}$, the heat flux vector q_i^C due to heat conduction in $\mathrm{B_t}$ is formulated as:

$$q_i^C = -L_0(\delta_{ij} - D_{ij})\frac{\partial T}{\partial x_j} \tag{2}$$

where L_0 is the thermal conductivity of the undamaged material.

Besides the heat conduction through the effective net area of the damaged material $\mathrm{B_t}$, heat transfer due to radiation though the cavity surfaces should be formulated. By calculating the gray-body radiation through a row of n cavities at an average interval of η in the characteristic length dx_i in RVE of $\mathrm{B_t}$, the heat flux vector q_i^R through cavity surfaces is formulated as

$$q_i^R = -L^R D_{ij}\frac{\partial T}{\partial x_j}, \qquad L^R = 4\sigma\varepsilon\eta T^3 \tag{3}$$

where σ and ε are the Boltzmann constant and emissivity. The quantity $L^R D_{ij}$ represents a fictitious thermal conductivity tensor due to radiation.

In view of equations (2) and (3), the heat conduction law and the equation of heat conduction in anisotropically damaged materials are expressed as follows:

$$\begin{aligned} q_i &= q_i^C + q_i^R \\ &= -L_{ij}^{EQ}\frac{\partial T}{\partial x_j}, \qquad L_{ij}^{EQ} = L_0(\delta_{ij} - D_{ij}) + L^R D_{ij} \end{aligned} \tag{4}$$

$$\frac{\partial}{\partial x_i}\left(L_{ij}^{EQ}\frac{\partial T}{\partial x_j}\right) + h = c_v \rho \dot{T} \tag{5}$$

where L_{ij}^{EQ} is the equivalent thermal conductivity in the damaged material. The symbols h, c_v and ρ, furthermore, are the rate of heat generation, specific heat and mass density, respectively.

After discussing the tensorial nature of the resulting equations of (4) and (5), the variation of the equivalent thermal conductivity L_{ij}^{EQ} due to the development of anisotropic damage D_{ij} is demonstrated.

Finally, the applicability of the resulting equations is discussed by applying them to the analysis of anisotropic creep damage of a thick-walled tube subjected to thermo- mechanical loading.