STRESS REVERSE AND RESIDUAL STRESSES IN DRIED MATERIALS

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ABSTRACT

Non-uniform shrinkage of saturated materials subjected to drying is the main reason for generation of internal stresses. The drying induced stresses in elastic materials are of temporary character and disappear after drying. This is however not the case when the stresses cause local inelastic strains [1]. In such circumstances the phenomenon of *stress reverse* may take place when the material dries and the drier surface attempts to shrink but is restrained by the wet material core. Then, the surface is stresses in tension and the core in compression and large inelastic tensional strain occur at the surface. Latter, under the surface with reduced shrinkage, the core dries and attempts to shrink causing the stress state to reverse. The reversed tensional stresses inside the material cause often internal cracks.

Another phenomenon that may occur in dried materials is called *the locked-up* or *residual stresses*. They arise when the material changes its mechanical properties during drying. Such stresses may occur, for example, in saturated clay-like materials that are viscoplastic, and in the course of drying become elasto-visco-plastic, elastoplastic, elastic and even brittle at the end of the process. If the change of mechanical properties is non-uniform throughout the body, the residual stresses mostly are present in materials after drying. Such stresses may have a substantial influence on the mechanical behaviour of materials during their utilization.

The residual stresses may elucidate, for example, why some dry materials shrink instead swelling during rehydration [1]. It was stated that the compressive properties are related to the morphology of the material. Loss of water and segregation of components that occur during drying makes the cell walls rigid. The outer layer becomes rigid and acquire considerable mechanical strength while the interior of the material is still of weak tensile strength. Amorphous domains are formed which add substantially to the mechanical strength of the material.

Similar phenomenon arise during quenching of steel. This process changes the structure and physical properties of carbon steel because a new structure called *martensite* arises in some domains. The accompanied to this process morphological phase transitions cause volume changes and induce internal stresses responsible in many cases for cracks of the material.

The above statements lead to the conclusion that residuals stresses in saturated bodies may arise during hydro-thermal processes if the material suffers shrinkage and its physical properties are changed in some domains. That means that for description of residual stresses should be applied a drying model, the material coefficients of which reflect changes of mechanical properties.

In this paper we present a mechanistic model of drying which allows to describe the mechanical changes of elastic and viscoelastic materials under drying [3]. Both materials reveal drying-induced stresses, however, the stress history in these two materials differ from each other both qualitatively and quantitatively. We want to show that none of these two materials will reveal residual stresses if the material coefficients are assumed to be constant. In order to describe the residual stresses, the material properties have to vary in the course of drying, that is, the material coefficients ought to be functions of moisture content.

We shall illustrate the problem of residual stresses on an example of kaolin-clay cylinder dried convectively. The system of differential equations was established for description of the heat and mass transfer as well as the drying stresses during both the constant and the falling rate periods. The

constructed on the basis of these equations numerical algorithm enable evaluation of the distribution of moisture content, temperature, and stresses in the dried body and their evolution in time in all stages of drying. The most relevant meaning of this model is that it enables description of a complete history of the drying induced stresses during the whole process up to residual stresses at the end.

A number of experimental tests were carried out to observe the variation of mechanical behaviour of the kaolin-clay material during drying and to determine the material coefficients as a function of moisture content. In this way we have expressed the changeability of physical properties of the material during drying, what enabled us to describe the residual stresses at the final stage of drying.

Figure 1a presents the time evolution of maximum circumferential stresses in the elastic and viscoelstic cylinder with constant shear and bulk moduli M = 450 kPa and A = 600 kPa and relaxation time $\tau = 5{\cdot}10^4$ min by drying in air humidity 35 % and temperature 70 ^oC .

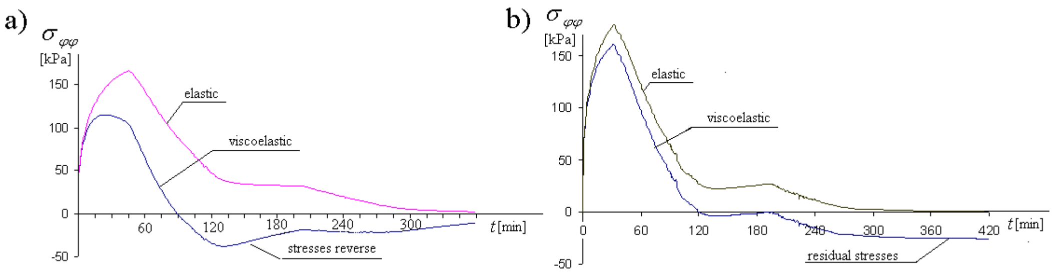

Fig. 1. Time evolution of maximum circumferential stresses in elastic and viscoelastic cylinder: a) with constant material coefficients, b) with material coefficients dependent on moisture content

It is seen that the plot of stress evolution for viscoelastic cylinder is different as that for elastic one. The stresses in elastic cylinder reach maximum in some instant o time and then tend to zero, while those in viscoelastic cylinder reach also maximum but of smaller value, next tend to negative values (stress reverse), and finally tend to zero. Figures 1b presents the time evolution of maximum circumferential stresses in the elastic and viscoelstic cylinder with variable material coefficients. It is seen that the circumferential stresses in viscoelastic cylinder become compressive and permanent in the final stage of drying. They do not tend to zero as those for elastic or viscoelastic cylinder with constant coefficients. This is because of change of material properties at the cylinder surface from viscoelastic to rigid at the final stage of drying. The relaxation time τ is near to zero for totally wet material (moisture content about 40%) and becomes very large ($\approx 10^6$ min) for dry body (moisture content about 6 %).

References

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