УДК 621.74
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SIMULATION OF STRESS-DEFORMED STATE OF CASTING DURING CRYSTALLIZATION

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МОДЕЛЮВАННЯ НАПРУЖЕНО-ДЕФОРМІВНОГО СТАНУ ВІДЛИВКИ ПРИ КРИСТАЛІЗАЦІЇ

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Keywords: simulation, stress-deformed state, casting
Ключові слова: моделювання, напружено-деформівний стан, відливка

In the production of castings for critical parts (for example, working and nozzle blades of gas turbine engines), the following defects are the cause of defects: hot cracks (Fig. 1), geometry mismatch (warping). These defects can occur for many reasons, including incorrect design of the gating-feeding system, incorrectly selected temperature regime, violation of mold manufacturing technology. One of the effective ways to solve these issues is the use of computer simulation of foundry processes such as ProCast, MagmaSoft, WinCast or SolidCast at the design stage.


Figure 1 – Cracks that occur during the casting of gas turbine engine blades due to high stresses in the casting

The physical essence of the investment casting process is that to obtain a casting, molten metal is poured into a ceramic shell - a mold, the internal cavity of which forms the surface of the resulting casting. The form and liquid metal have given temperatures, thermal, shrinkage and deformation properties. The cooling process of the casting is, as a rule, uneven due to the presence of thin and massive parts in it, the uneven thickness of the walls of the mold, and because that part of the casting borders directly on the external environment. As a result of these reasons, the geometry of the casting may change, and its destruction may occur. On the other hand, the form can either prevent these changes or collapse itself under the influence of casting and internal stresses [1].

These processes can be controlled using mathematical simulation of the stress-strain state of the casting during its cooling from the liquid state to low temperatures.

To calculate stresses and strains in castings and molds, it is necessary to use a medium model that will describe the behavior of materials in the process of cooling and the occurrence of stresses in them. The stress state that occurs in the metal and ceramic mold during cooling is described by the true stress tensor. The values of the stress tensor components are determined from the ratios of the thermoplastic material.

In the model under consideration, the elastic properties are determined by the elastic modulus *E*, Poisson's ratio *υ*, modulus of linear thermal expansion *α*, which depend on temperature *T*:

$$E = E(T),\ \upsilon = \upsilon(T),\ \alpha = \alpha(T). \qquad (1)$$

The functions *E(T)*, *υ*(*T*), *α*(*T*) will be considered given. Let's define the average stress:

$$\sigma = 1/3\left(\sigma_{11} + \sigma_{22} + \sigma_{33}\right). \qquad (2)$$

Then the relative change in the volume of particles (for small deformations):

$$\Theta = \varepsilon_{11} + \varepsilon_{22} + \varepsilon_{33} \qquad (3)$$

According to the Dugamel-Neumann law, Hooke's volumetric law, taking into account temperature changes, has the form:

$$\sigma = \frac{1}{3}\left[\frac{E(T)}{1-2\nu(T)}\right]\left(\Theta = 3\alpha\Delta T\right). \qquad (4)$$

To describe the dependence of the stress tensor deviator

$$S_{ij} = \sigma_{ij} - \sigma\delta_{ij},\ \sigma_{ij} = s_{ij} + \sigma\delta_{ij}, \qquad (5)$$

где $i, j = x, y, z$.

The stress tensor deviator at the current time is proportional to the difference between the current strain tensor deviator and the plastic strain tensor deviator (the plastic strain tensor coincides with its deviator), i.e.:

$$S_{ij}(t) = D\left(e_{ij}(t) - e_{ij}^{P}(t)\right), \qquad (6)$$

where e_{ij} - current deformation deviator,

e_{ij}^{P} - plastic strain tensor deviator.

In the translationally isotropically hardening model, it is assumed that e_{ij}^{P} - the deviator corresponds to the point of complete unloading and the coefficient *D* varies depending on the deformation process and temperature *T*.

The kinetics of change e_{ij}^{P} is defined as follows:

$$\Delta e_{ij}^{(P)} = \left[e_{ij}(t) - e_{ij}^{(P)}(t)\right] - \frac{S_{ij}(t)}{2\mu(T)}. \qquad (7)$$

Since the described relations determine the stress tensor deviator up to the specification of the coefficient *D* depending on the deformation process, to determine the dependence of this coefficient e_{ij}, a simple process is considered that is easily implemented in the experiment - uniaxial tension of the sample. Then the dependence of *D* on the deformation process can be reconstructed from the experimental data.

To solve the problem of determining stresses and strains in casting and a mold, the method of local functionals is used, which is a modification of the finite element method.

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