NUMERICAL METHOD OF CALCULATION OF THERMOMECHANICAL STATE OF CYLINDRICAL BODIES UNDER GROWING AND SUBSEQUENT CYCLIC LOADING

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Additive manufacturing (AM) conceptually changes over the applied methods and materials being created. AM introduces some new philosophy as well as technological theoretical approaches to desired structures which cannot be produced using traditional methods.

The paper deals with the numerical simulation of residual and current thermo-mechanical and microstructural states of cylindrical parts subjected to a multi-layer liquid metal surfacing as well as their durability under subsequent thermal and mechanical loading.

Statement of the problem is based on the quasi-static thermomechanics of inhomogeneous inelastic bodies. As constitutive equations the unified model Bodner-Partom flow is utilized. The experimentaly defined dependences of model parameters on temperature and phase composition are taken into account [1].

The calculation of the structural state is performed using thermo-kinetic (CCT) diagrams of decay of supercooled austenite. Moreover Koistinen-Marburger equation of phase accumulation during microstructure martensite transformations is applied.

As materials, low alloyed steels, low carbonic and martensitic steels are used. Temperature dependent thermal characteristics as well as the parameters for separate microstructural phase of steel were determined from experimental data. The current values of these parameters for multiphase state were calculated using a linear mixture rule.

The process of a multi-layer surfacing of cylindrical bodies is simulated within the model of growing bodies. To meet the non-classical conditions on the surface of metal deposition the conception of “eigen strain and temperature” is implemented. Scheme of “bead by bead” and simplified scheme “layer by layer” deposition are employed (Fig. 1 a, b).

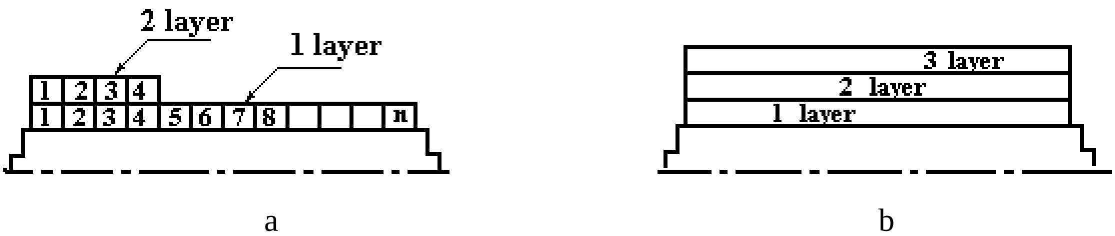


Fig. 1

To solve the problem of three-dimensional spiral surfacing and subsequent operational loading an approximate scheme is developed. The scheme proposed uses an axisymmetric approach to the problem of the modeling of residual stress formation while surfacing. The problem of generalized plane strain of long cylinder under operational loading with accounting of the residual strains is formulated.

Finite element method developed is combined with the implicit time stepping scheme for integrating the unsteady equations and iterative procedure for solving nonlinear boundary value problems of thermomechanics at each time step. Microstructural state of each instant of time at each point of body is also calculated and materials parameters are to be corrected. Isoparametric quadrilateral element is utilized.

The approach developed is being tested on the example of a roller for hot rolling of 51CrMnV4 steel having two-layer surfacing of working side surface. The first layer (sub-layer) is surfaced with steel DC01, and the second (external) layer is 25Cr 5VMoSi steel (Fig. 2, 3).

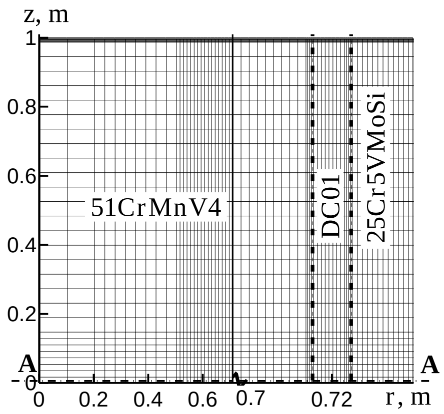


Fig. 2

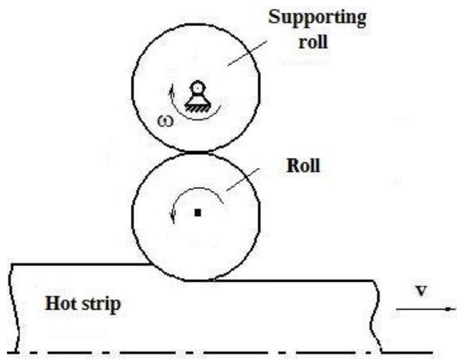
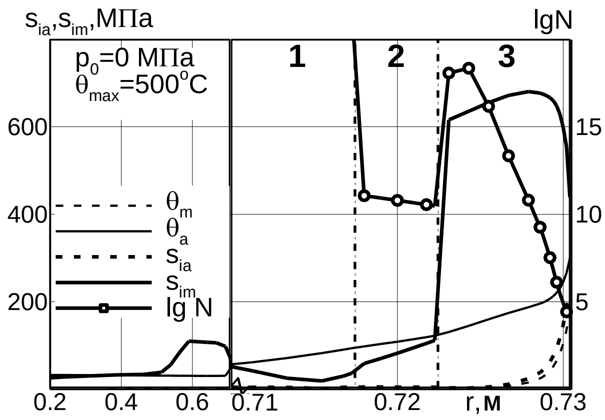


Fig. 3

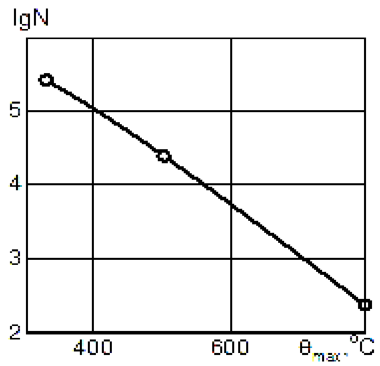
The residual stress calculated were compared with stress measured by means of the “Hole Drilling Method” (ASTM Standard E837). The results agreement is reasonably good.

Being calculated the average and peak values of the parameters of the stress state in conjunction with the original properties of the material are used in the multicyclic Manson-Birger equation of the fatigue life to make an estimate of the durability of the surface layer, sublayer, and the base metal.

Calculated radial distribution of amplitude (index a) and mean (index m) components of stress intensity s_i, temperature θ and cyclic endurance $\lg N$ are shown in Fig. 4 a, were 1 indicates base metal, 2 – internal layer and 3 – external heat resistant layer. Dependence of external layer fatigue life on maximum cyclic temperature is shown in Fig. 4 b.



a



b

Fig. 4

Approach developed provide a way of estimating the residual stress-strain state of members subjected to multilayer material deposition as well as makes it possible to evaluate its strength under subsequent exploitation with thermo-mechanical loading.

[1] I.K. Senchenkov, O.P. Chervinko and M.V. Banyas (2013). *Modeling of thermomechanical process in growing viscoplastic bodies with accounting of microctructural transformation. Encyclopedia of Thermal Stresses. R.B. Hetnarsky (ed.)*, Springer Reference, **6**, 3147 – 3157.