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An Approach to Numerical Modeling of Selective Laser Melting

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Abstract

Technological parameters of selective laser melting determine the quality of the parts produced: porosity, residual stresses and so strength and plasticity. Numerical modeling can help understand this dependence. The modeling process must account for the fact that typical sizes of metal powder particles, used for selective laser melting, are comparable (near equal) to the diameter of the laser beam, so considering powder a continuum is not fully correct. It is shown that LS-DYNA finite element code has enough capability to model important features of the process – heat exchange, melting, contact interaction of the particles.

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Keywords: selective laser melting; numerical modeling; finite element analysis; LS-DYNA.

1. Introduction. Statement of the problem

Selective laser melting (SLM) is a technological process allowing to obtain metal parts of arbitrary complex geometry [1]. Properties of the parts – porosity, strength, ultimate strain – strongly depend on the process technological parameters [2,3]. Number of applicable metals and alloys is big enough, so determination of optimal technological parameters is an actual task. Experimental search for optimal parameters not only expensive and time consuming [4-6], but do not give detail understanding of the process features like residual stresses, porosity, etc., and numerical modeling could help to gain a better insight.

Growing interest to the SLM process inspires a number of publications concerning to the process modeling. First, those publications discuss characteristic features of the process like melting and evaporation, heat transfer in porous media, influence of gravity and capillary forces, formation of melt stripe or separate drops due Marangoni effect,

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solidification and phase changes causing residual stresses, etc. Second, some publications implement numerical models, concerning certain features of the process.

Most of models treats the metal powder, used as a workpiece, as a homogeneous media [6-13]. However, diameter of the laser spot, heating the powder, is close to the diameters of powder particles – about 0.05 mm. The "homogenous" approximation of the material can be used as a first approach, but "inhomogeneous" model, taking into account separate particles, could be useful for more accurate modeling.

Special apparatus created in South-Ural State University [14] provides the production of metal powder with particles of almost perfectly spherical shape. So it was assumed that numerical model can be built as a set of spheres, placed in a container. It was also assumed, that the model must descripts

- heat transfer, including irradiation heating by laser beam, heat transfer inside a particle and heat exchange between contacted particles (due irradiation an heat transfer through the media between particles);
- mechanical behavior of the particle material in wide range of temperatures, including melting and viscous effects, and also volumetric strains caused by heating and phase change (for prediction of residual stresses);
- contact conditions between neighboring particles, influencing both heat transfer and geometry of melting particle;
- forces, acting on a particle (gravity, capillary force [15,16], possible reactive force from evaporating material).

Complexity of the process makes it difficult obtaining of an analytical solution, and numerical – finite element – approach was selected as a basis for the model. LS-DYNA finite element code [17], specially designed for highly nonlinear tasks, seems a suitable tool for modeling. Nevertheless, modeling faces some difficulties.

2. Formation of a powder layer

The first stage of the selective laser melting process is formation of a powder layer that would be subsequently melted by scanning laser. Particles of the metal powder can be of different size, and the model must contain suitable number of particles to obtain statistically significant solution. To generate a model with big enough number of spherical particles, preprocessor of ANSYS finite-element package [18] was used. Special procedure, written using APDL (ANSYS Parametric Design Language), generates predetermined number of spherical volumes, initially located in the cubic grid nodes, and a comprising container. The particles radii were generated by random number generator with the distribution close to the experimentally obtained for particles produced by the apparatus described in [14]. All particles were meshed using only hexagonal finite elements. After creating in ANSYS, the model was transferred to LS-DYNA, and falling of the particles onto the container bottom due gravity was modeled. It is necessary to note, that stability condition for explicit dynamic solution in LS-DYNA demands small time step (less than finite element size dividing by the speed of sound in the material, i.e. for steel sphere of 0.050 mm having at least 4 elements per diameter – minimum for hexagonal mesh – the time step is about $2 \cdot 10^{-9}$ s), and to speed up the solution the gravity can be substantially increased with addition of appropriate damping.

To estimate correctness of this solution step the calculated apparent density was compared with the experimental one [15]. "Apparent density" of the model was calculated as a fraction of a secant plane, parallel to the container bottom, occupied with the material of spheres – Fig. 1. For the planes not very close to the top of the spheres layer, this fraction is nearly stable (0.43-0.45) and close to the experimental one (0.48 – [15]).

Increase of apparent density can improve results of production, decreasing the porosity. In real process the density increased by roll up or other similar measures. Tests show that modeling of vibration of the container (before calculation of the apparent density) allow to increase the density from 0.45 to 0.57.

3. Heating and melting

Modeling of the main stage of the SLM-process – heating, melting and formation of solid material- demands a model, working appropriately in case of large deformation. One of possible ways is usage of Eulerian approach – finite element mesh is connected with the space and not with the material, and the materials can flows through the mesh. This technique is realized in LS-DYNA, and allow to model arbitrary large deformation of melted material. As an example Fig. 2 shows deformation of melted particles in simplified situation – spheres of the same size are