Numerical Simulation and Forecasting of Mechanical Properties for Multi-Component Nonferrous Dispersion-hardened Powder Materials

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Abstract

A new mathematical simulation technique for physico-mechanical properties of multi-component powder materials is proposed in this paper. The main advantage of the technique is that finite elements representing different components are placed into a common mesh and may exchange their properties. The output data are properties of material after sintering. The technique allows us to investigate the influence of each component of a material on the properties and distribution of properties inside the sample. The comparative analysis of materials with different compositions is based on simulation results that are well concordant with the results of the laboratory experiments.

Keywords : multi-component, finite element, distribution, LS-DYNA

1. Introduction

The functional powder materials refer to the most perspective materials which have specified physico-mechanical properties. The antifriction multi-component powder materials refer to functional materials, in which the required complex of physico-mechanical properties is reached by optimization of the volume fractions of components in the material at a specified porosity value [1].

The necessity of physico-mechanical properties prediction, while taking into account the mutual influence of all the components and porosity, required the development of more adequate and reliable methods for multi-component powder materials [2].

2. Mathematical Model and Simulation

The mathematical model of multi-component material and mechanical test is a system of constitutive equations, which define the physical and mechanical properties of components. The finite elements that describe different components of material are placed in a common mesh. It allows the possibility of taking into account interactions between components. The input data are volume fractions of components, their property in compact state and specified value of porosity (Table 1). The elasto-plastic model of material is applied to all components. Porosity is also a component of the powder material and zero-elements are used for its modelling in the proposed model. The volume fraction of zero-elements is equal to the given porosity of the material. The independent parameters are nodal displacements. Taking into account the thermomechanical coefficients, the Cowper and Symonds

equation for stress intensity σ_i looks like [3]:

$$\sigma_i = \left[1 + \left(\frac{\dot{\varepsilon}_i}{C}\right)^{\frac{1}{p}}\right](\sigma_0 + \beta E \varepsilon_i), \qquad (1)$$

where σ_0 – is the initial yield stress of a component;

ε_i, $\dot{\varepsilon}_i$ – are the strain and strain rate intensities;

E – is the Young's modulus;

$\beta = k_t k_\upsilon k_\varepsilon$ – is the hardening coefficient of a component.

Table 1. Components of material and their properties

	Component	Volume fraction, [%]	Density, [kg/m³]	Young's modulus, [MPa]	Poisson's ratio	Yield stress, [MPa]	Ultimate stress, [MPa]
1	Copper	70-90	8940	$1.20 \cdot 10^5$	0.33	120	220
2	Nickel	10-30	8897	$2.03 \cdot 10^5$	0.31	210	450
3	Cobalt	5	8900	$2.09 \cdot 10^5$	0.31	200	350
4	Iron	2	7850	$2.10 \cdot 10^5$	0.28	200	280
5	Manganese	1	7470	$1.98 \cdot 10^5$	0.22	210	430
6	Titanium	3	4505	$1.10 \cdot 10^5$	0.34	160	530
7	Graphite	1	1800	$0.85 \cdot 10^5$	0.43	100	120
8	Porosity	10-30	0	0.00	1.00	0	0

The values of σ, ε, E, Poisson's ratio v and density ρ in a given area of sample may be expressed in the following way [3]:

$$\sigma = \frac{\sum_{j=1}^{n} \sigma_j}{n} , \quad \varepsilon = \frac{\sum_{j=1}^{n} \varepsilon_j}{n} , \quad E = \frac{\sigma}{\varepsilon} , \quad v = \frac{\varepsilon_{xy}}{\varepsilon_z} , \quad \rho = \frac{\sum_{j=1}^{n} \rho_j}{n \sum_{i=1}^{m} \delta_i} , \quad (2)$$

where n – is the number of finite elements in given area;

   m – is the number of components in the material;

   δ_i – is the volume fraction of each component.

Table 2. Calculated and experimental properties

Material	Volume fraction, [%]		Type of data	Porosity, [%]	Density, [kg/m^3]	Young's modulus, [MPa]	Poisson's ratio	Ultimate strain, [%]	Yield stress, [MPa]	Ultimate stress, [MPa]
	Copper	Nickel								
1	90	10	S	10	8046	$1.53 \cdot 10^5$	0.42	34	320	430
			E	8	8110	$1.65 \cdot 10^5$	0.40	36	340	460
2	80	20	S	20	7152	$8.75 \cdot 10^4$	0.38	30	280	370
			E	17	7350	$9.15 \cdot 10^4$	0.35	33	300	390
3	70	30	S	30	6560	$5.86 \cdot 10^4$	0.35	30	250	300
			E	32	6245	$5.56 \cdot 10^4$	0.31	28	230	270

S – the simulation results; E – the experimental results.

The results of the prediction of physico-mechanical properties were calculated for the investigation of copper-nickel powder material with porosity 10–30 % by using the LS-DYNA solver. The technology for obtaining the samples consists of the following operations: moulding of powder mixture, sintering at 950 ^{0}C into the synthesis-gas medium for 3.5 hours, repeated moulding up to porosity 10–30 %, homogenizing annealing into the synthesis-gas medium at 960 ^{0}C for 1 hour, hardening in water.

3. Summary

The new technique for forecasting the properties of multi-component powder materials was proposed on the basis of physico-mechanical properties of its initial components by using the finite element method and LS-DYNA. The distribution of density inside a sample of the multi-component material was obtained. The influence of copper, nickel and porosity on properties was investigated.

4. References

1. Michailov O.V., Shtern M.B. *Numerical modelling of pressing processes of powder articles with complex shape in rigid moulds: the influence of pressing scheme at the distribution of density,* Powder Metallurgy, Vol. 3/4, (2003), p. 7-16.

2. Information on http://www.qform3d.ru.

3. LS-DYNA Theoretical Manual (Livermore Software Technology Corporation, May, 1998).