HIGH-STRENGTH STATE OF TWO-PHASE COMPOSITE MATERIALS PART 2. CERMETS

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Numerical simulation of the cooling process was carried out to determine the residual stress-strain state of diamond-bearing and tungsten-cobalt hard alloys after sintering. The results show that the thermal stresses of these materials increase their tensile strength. The concentration dependence of the tensile strength of alloys of the WC–Co system is analyzed.

Thermal stresses affect the deformation diagram of a composite material in comparison with residual thermal stresses. The tensile strength of the material can be increased by generating a residual stress-strain state (SSS) of a specific type in the material.

In the material which consists of a system of parallelly connected alternating plates of phases, the tensile strength in the longitudinal direction of the plates increases as a result of the fact that the plate with a high thermal expansion coefficient (TEC) stretches and compresses the brittle plate for which the tensile stresses are critical. In this case, an increase of the tensile strength of the material depends mainly on the ratio of the differences of the free thermal and limiting strains of the phases. The structural parameter (ratio of the thickness of the plates of the phases) affects only the tensile strength.

The tensile strength of the material whose brittle phase has the form of a parallelepiped is increased by compressing band $\alpha$ [1] as a result of the difference of the TEC of the bands as well as by additional compression of parallelepipeds of the brittle phase by the plate with $z \neq 0$. In the material with the given structure, in the range of the permissible values of the structural parameters and parameters of the physicomechanical properties it is possible to define the values at which the tensile strength of the material increases [1].

We shall now generalize relationships governing the formation of thermal stresses in the isotropic material with an arbitrary structure ensuring high-strength of this material, in...
the form of the following two necessary conditions after residual SSS.

1. The tensile strength of the material is determined by its weak cross section. Therefore, the volume of the material must contain a continuous bound field of compressive normal stresses intersecting any of its sections.

2. The maximum normal stress in the brittle phase should be considerably lower than its tensile strength because this stress is "harmful."

There are a large number of cermets for which these conditions are satisfied. Since these materials are present in a composition of a ceramic phase with metals or metallic alloys, the large differences in the TEC of the phases usually cause residual thermal stresses during cooling.

In the cermets, the metallic phase is referred to as the binder and the continuous bound solid formed in the volume of the material by the binder as the matrix. In subsequent considerations, the grain will be represented by the grain of ceramic phase. The continuous bound solid, consisting of ceramic grains, will be referred to as the skeleton.

We shall examine two ultracermets in which the brittle properties of the ceramics are improved as a result of the ductility properties of the metallic phase. One of these materials is VK20 hard alloy, the other a diamond composite with a Cu–Sn–Ti alloy as a matrix. The content of this alloy is 40 vol. % (Fig. 1). In the stage of liquid-phase sintering, the examined two-phase composites are characterized by zonal isolation of the particles of the refractory phase which leads to formation of a structure with the nonuniform distribution of the binding phase [2].

The relationships governing formation of the residual thermal SSS were examined by numerical simulation of the process of sintering the cermet by solving the problem of thermo- elastoplasticity in a plane stress formulation. Numerical simulation was carried out using a TANDEM automated computing system by the method of finite elements [3].

The calculation regions including several grains were represented by typical areas on the sections prepared from these cermets (Fig. 1). It was assumed that the binder is characterized by plastic linear hardening and the ceramic phase deforms elastically. The contour of the calculation regions is right-angled. The right-angled region can freely deform but in such a manner that the unknown displacement of the edge points along the normal to the boundary differ. This requirement ensured that the right-angled form of the region during thermal shrinkage as a result of cooling was unchanged. It is evident that this definition of the unknown boundary-value conditions which simulate interaction with the remaining part of the composite does not take into account the individual specific features of this structure of the calculated region but is most preferable.

It is evident that the temperature gradient in the calculation region can be ignored because this region is small. Therefore, it was assumed that the temperature changed smoothly and was the same at all points of the region. The initial cooling temperature was assumed to be equal to 800°C because at temperatures above 800°C the binding phase is too plastic to withstand any loading, and the residual thermal stresses are eliminated by local creep.

As a result of the fact that the adhesion strength of the interphase boundaries had not been sufficiently studied by experiments, it was assumed that this strength is higher than the strength of the phases present in the material because after sintering there was no failure at the interphase boundaries in these materials. Therefore, it was assumed that bounding at the phase boundaries is complete.

As a result of solving the problem we obtained calculated fields of displacements, strains, and stresses at 100°C steps of the cooling process of the sintered material. In addition, we constructed fields of types of materials containing regions of failure, and the strength safety factor coefficients for unfailed regions were determined.

Since some of the data obtained in simulating sintering the VK20 alloy were published in [4] we shall examine in greater detail simulation of the sintering process of the diamond composite.

Analysis of the results show that the binder deforms plastically from the very start of cooling. Plastic yielding starts in the thinnest interlayers between the grain. Gradually, the plastic strain affects the entire region of the binder, with the exception of small sub-regions at the joints of the grains which are in the uniform tensile loading conditions.