These relationships can be used to produce components by the powder metallurgy methods. The processes used for forming these components must support the formation and retention of the sufficient number of initial boundaries and boundaries of deformation origin. The most efficient processes in this respect are rolling after pressing and extrusion, and also rolling into strips with subsequent coiling and rolling out.

LITERATURE CITED


LIQUID-PHASE SINTERING OF MOLYBDENUM-COPPER PSEUDOALLOYS


Shrinkage as a result of regrouping of powder particles [1] is the main process in formation of molybdenum-copper pseudoalloys by the liquid-phase sintering method and also of other systems with very low solubility of the solid in liquid phase. The effect of the amount of the low-melting phase on the characteristics of the shrinkage process as a result of regrouping of the powder particles in liquid-phase sintering have been studied most comprehensively in [2-5] where main attention was given to the dependence of shrinkage on the amount of the low-melting phase. In [2] shrinkage was examined in the largest range of the ratios of the volumes of refractory to low-melting phase at the constant initial relative volume of the refractory phase in the specimen (ratio of the volumes of the refractory phase and the specimen). The results show that the shrinkage and capillary force causing shrinkage during the variation of the initial degree of filling of the pores of a network with the melt passes through a maximum which is positioned in the range in which the pore space is filled with the melt to 50-60%. However, it should be mentioned that during sintering the porosity of the specimen and shrinkage rate decrease and the degree of filling of the pore space by the melt increases. Consequently, shrinkage characterizes only indirectly the dynamics of the process.

In this work, in examining shrinkage the main attention is given to determining its rate in the initial stages of sintering in which the porosity of the specimen and relative volume of the liquid phase in the specimen differ only slightly from the initial values. The dependence of the shrinkage rate in the initial stages of the process on the liquid phase content of the specimen characterizes the dynamics of the process of sintering the real powder mixtures. The kinetics of sintering in the wide range of the content of the liquid phase in the specimen can be examined only by the liquid-phase sintering method with saturation [2]. In this method, a specimen of a refractory component is saturated with the given amount of the low-melting component and shrinkage is recorded by some method. In this work, the shrinkage of the specimens was determined with a dilatometer [6] and recorded on diagram paper. Specimens of molybdenum powder or a mixture of copper and molybdenum powders in the form of a cup were placed in the measuring cell of the dilatometer and the metered amount of remelted copper was poured into the cavity of the specimen (Fig. 1). The use of the specimens of this form accelerates the saturation process, ensures uniform saturation, and the amount of copper added to the specimen can be accurately metered.

Fig. 1. Diagram of measuring shrinkage in sintering. 1) support areas of the dilatometer (alundum), 2) specimen of pressed powder, 3) cavity for loading copper; 4) thermocouple.

Fig. 2. Dependences of relative shrinkage $\Delta l/l_0$ and shrinkage rate $\omega$ on sintering time of the specimens of batch 1 at $V_{Cu}:V_{Mo} = 0.6$.

The dilatometer includes a spring-type compensator of the mass of the moving part and, consequently, the load on the specimen in shrinkage measurements does not exceed 100 Pa. Reference experiments showed that this load had no effect on the value of shrinkage in these conditions.

The specimens were prepared from a molybdenum powder produced by reducing ammonium molybdate (TU 48-19-310-80); the oxygen and iron content of the powder did not exceed respectively 0.3 and 0.02%, the mean surface of the powder was 0.5 m$^2$/g, the mean grain size 20 $\mu$m. The experiments were conducted on copper powder of MPS-1 grade with a mean grain size of 10 $\mu$m and electrolytic copper of V3 grade remelted in vacuum in graphite crucibles.

The specimens were prepared from molybdenum powder (batch 1) and a mixture of powders of molybdenum and copper (mass content of copper 13.7%, batch 2). A small amount of the low-melting component is added to the composition of the compact with subsequent saturation with the same component in liquid-phase sintering in production of components from pseudoalloys. This widens the technological possibilities of the method. Since it is not possible to ensure the equal density in the volume of the specimen of the vessel form during its preparation by compacting, the specimens were produced by two-side compacting cylindrical blanks followed by drilling a hole in them. The blanks were compacted with a limiter so that the relative volume of molybdenum in the specimens of both batches was $0.5 \pm 0.006$.

Liquid-phase sintering of the specimens was carried out directly in the measuring cell of the high-temperature dilatometer at a temperature of 1150°C which is used in the production of molybdenum-copper pseudoalloys, for 1 h in hydrogen ($3 \times 10^4$ Pa) produced by dissociation of titanium hydride. The heating time from 1000 to 1150°C was 6 min. When the melting point of copper was reached the specimens started to shrink rapidly. With melting of copper and saturation of the specimens with copper the shrinkage rate increased and passed through a maximum (Fig. 2). The porosity of the specimens after the experience was determined by hydrostatic weighing. Microstructural and x-ray spectrum microanalysis investigations showed that copper is uniformly distributed in the volume of the specimen.

Figure 3a shows the time dependences of the relative linear shrinkage $\Delta l/l_0$ ($l_0$ is the initial height of the specimen) of the specimens of batch 1 at various values of the ratios of the volumes of copper and molybdenum $V_{Cu}:V_{Mo}$. Sintering of the specimens produced from the mixture of the powders of copper and molybdenum (batch 2) was accompanied by less extensive shrinkage at the same value of the ratio $V_{Cu}:V_{Mo}$ (Fig. 3b). This is explained by the higher mobility of the powder particles in the specimens of the first batch as a result of the lower pressure during forming of the specimens (90 MPa). To ensure the identical relative volume of molybdenum in the specimens of the two batches the compacting pressure in compacting the Mo-Cu mixture was 300 MPa.

High shrinkage in sintering the specimens of the first batch is accompanied by the lower porosity of the specimens after sintering (Fig. 4). The limiting shrinkage of the specimens