Graphite in antifriction sintered materials acts as an alloying element and an antiscuffing addition. Depending on the composition of composites containing metals that react with or are inert to graphite, the effect of the latter on the sintering process and on the properties of the resultant materials may vary. Up to now, however, for multicomponent composites such as metal–graphite materials of the systems Fe–Ni–C and Ni–Cu–C, this problem has not been investigated at all.

The object of the present work was to study the sintering process of metal–graphite materials based on nickel alloys and the phase and structural changes occurring in them as a result of sintering. Composites containing 80% Ni (PNE, GOST 9792–61 standard), and 20% Fe (PZh1M, GOST 9849–61 standard) or 20% Cu (PM, GOST 4960–49 standard), to which was added 30 or 50 vol.% of low-ash graphite manufactured by the Zaval'esk Graphite Combine, were chosen for investigation.* Determinations were made of the densification kinetics and linear and volume changes of the materials depending on their graphite content and the nature of the element added to nickel.

Pressed specimens, 21 x 4 x 3 mm in size, had a density of 78–79%, as determined by hydrostatic weighing. Sintering was performed in a vacuum dilatometer at temperatures ranging from 1050–1250°C, with isothermal holding for 2 h at each temperature. The rate of heating of specimens to the required temperature was 50°C/min.

Dilatometric curves, showing relative changes in specimen length during heating and cooling, established that, in the temperature ranges 20–700 and 20–800°C for nickel–copper and nickel–iron graphite materials, respectively, Δl/t is proportional to temperature. With rise in temperature, the value of Δl/t for graphite-containing compacts rises, the extent of the rise being the greater the lower the graphite content. For graphite-free mixtures, heating to temperatures above 900°C in the case of Ni–Fe alloys and 950–1000°C in the case of Ni–Cu alloys results in an appreciable linear shrinkage of compacts, which is attributable to the sintering of the nickel matrix.

Curves of relative changes in length as a function of isothermal holding time (Fig. 1a) show that linear shrinkage is particularly marked during the first minutes, after which the rate of densification falls and subsequent holding during sintering is characterized by the simultaneous propagation of two opposing processes, volume growth and shrinkage. Here the shrinkage of Ni–Fe alloys is more pronounced than that of Ni–Cu alloys, which is partly attributable to dimensional changes due to α–γ transformations in iron and a decrease in the coefficient of linear expansion during the formation of Fe–Ni alloys. Apart from this, the

*Deceased.

†PNE is an electrolytic nickel powder, PZh1M is a fine reduced iron powder of 98.5% purity, and PM is a copper powder of 99.5% purity—Publisher.

The difference between the partial diffusion coefficients of nickel and iron is much less than that between the corresponding coefficients of nickel and copper [1].

The graphite separates the metallic particles and reacts with their surface oxide films. These factors, together with the evolution of gases adsorbed on graphite, whose escape from the zones of contact is hindered because some of the graphite inclusions may be completely isolated from open pore channels, help to break or loosen the contacts and increase the specimen volume. When nickel contains an addition of copper, which is more ductile than iron, blockage of graphite inclusions in the contact zones is facilitated, as a result of which compacts from Ni-Cu-C powders exhibit a greater increase in volume (Fig. 1a). The higher the temperature, the more intense is the shrinkage of parts being sintered, which, however, decreases with increasing graphite content of the material (Figs. 1b and 2). The fall in shrinkage with rise in temperature for a Ni-Fe alloy appears to be due to more rapid appearance of solid solutions of these metals, whose strength exceeds those of the starting metals iron and nickel; the high strength of the solid solutions, however, inhibits diffusional creep.

Raising the sintering temperature promotes the propagation of heterodiffusion processes in the remaining Ni-Cu contacts and pore formation, which accelerates sintering and intensifies shrinkage [2]. As the volume fraction of pores is much less in a Ni-Cu alloy with 50 vol. % C than in a similar alloy with 30 vol. % C, the shrinkage of the latter during holding at temperature will also be less.

The sintering process in the system Fe-Ni-C is similar, being controlled by the same factors that were noted when examining the differences in the behavior of Ni-Cu and Ni-Fe alloys. It must also be taken into account that the graphite in the system Fe-Ni-C reacts with the iron (in both the presence and absence of nickel), resulting in the formation of solid solutions. Appreciable concentration heterogeneities may accelerate sintering, because the self-diffusion coefficient of iron increases with rise in the carbon content of austenite [3]. However, a very high graphite content may disturb metallic contacts to such an extent that the diffusion processes are suppressed and shrinkage decreases.