MICRODEFECTS IN PARTICLES OF ATOMIZED HIGH-SPEED STEEL POWDERS


The manufacture of alloy steel and alloy powders by atomization involves a number of physicochemical, gas-hydrodynamic, and heat-transfer processes. Defect formation in atomized powders is associated chiefly with the metallurgical processes of melting of metal of the required composition and its transfer to the tundish and also with the atomization of the metal by a neutral gas. Below are given descriptions of typical defects found in atomized powders, together with the results of an investigation into the mechanism of formation of these defects and suggestions concerning methods of their prevention. A high-speed steel powder produced by atomization of molten metal in an unsealed unit, i.e., in an oxidizing atmosphere and a powder atomized in a hermetically sealed unit provided with a neutral atmosphere were chosen for investigation.

Oxide Films. Atomization in an oxidizing atmosphere results in the formation of surface oxide films on powder particles. The thicknesses of such oxide films were measured metallographically on specimens pressed at room temperature from a mixture containing an atomized powder and a carbonyl nickel powder in the ratio 1:4 (Fig. 1). A study of the conditions of oxide film formation has demonstrated that oxidation of a powder occurs chiefly while its particles are in the molten state. Because of this, the thickness of such an oxide film varies and is related to the rate of cooling of the powder particles in the solidification range, i.e., to the particle size [1].

The mean thickness of the oxide films on particles produced in the unsealed atomization unit was 0.20-1.0 $\mu$ at an oxygen content in the powder of 0.12-0.20%. The powder varied in color from dark gray to black. Atomization of liquid metal in an argon atmosphere in the hermetically sealed unit enabled the oxygen content to be lowered to 0.01-0.02% and yielded a powder having a silvery color. Some of the particles had temper colors — golden, blue, and dark brown, corresponding, according to literature data, to a film thickness of 0.02-0.06 $\mu$. As dimensions of this order are not resolved by the optical microscope, metallographic examination fails to detect oxide films on such a powder.

Slag Inclusions. Dark slag particles in the form of "crusts" completely or partially enveloping metal particles were observed in the powder in the as-poured condition and metallographically (Fig. 2). The slag-surrounded particles frequently contained internal globular oxide inclusions. Metallographic, petrographic, and x-ray structural studies revealed that the slag particles were identical in composition with the furnace slag, which consisted mainly of (Mg, Fe) O $\cdot$ SiO$_2$, 2MgO $\cdot$ SiO$_2$, MgO, CaO $\cdot$ FeO $\cdot$ SiO$_2$, 2CaO $\cdot$ SiO$_2$, a colorless glass, and a small quantity of a spinel of complex composition. At this phase composition the slag inclusions in the powder were enriched to a considerable extent in ferrous oxide, i.e., they were atomized particles of the furnace slag.

The slag particles in the powder were counted by determining, with the aid of a binocular magnifier (at a magnification of 30 diameters), their percentage on 3000 powder particles in a narrow powder fraction ($\leq 100 + 80 \mu$) corresponding to the maximum in the particle size distribution curve.

To obtain powder free from slag inclusions it was necessary to prevent slag from reaching the atomization zone. This was done by thickening the slag in the furnace before pouring with a lime addition and

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removing as much of it as possible. The last batch of metal (~1 kg) was frozen in the tundish with a steel rod, which prevented the slag from breaking through into the atomization chamber. As a result of these measures the powder, which before their adoption contained 0.1-1.0% and in some cases up to 2.5% of slag, became almost completely free from slag inclusions.

Nonmetallic Inclusions. The atomized powder contained, in spite of very high drop solidification rates ($1 \times 10^4$-$1 \times 10^5$ deg C/sec), numerous nonmetallic inclusions, located as a rule not only on the surfaces of its particles (Fig. 3a) but also within them (Fig. 3b). In sintered blanks the inclusions were slightly deformed, filling the spaces between the particles, while in worked metal they constituted ductile or brittle silicate particles. During the period of development of an atomization technique the inclusion size attained 100-150 $\mu$, which in worked metal corresponded to grain size No. 5 or higher on the ductile and brittle silicate grain size scale to GOST 1778-70.

Unlike the atomized slag inclusions, the coarse nonmetallic inclusions were difficult to detect during an examination of the powder in the as-poured condition because they were transparent and many of them were located within the particles. Because of this, such nonmetallic inclusions should be examined only in pressed specimens.

Petrographic analysis revealed that the nonmetallic inclusions constituted vitreous phases of complex, variable composition. Further evidence in support of this finding was provided by the fact that their refractive indices varied widely, from 1600 to 1700.

A microanalysis carried out by A. N. Kurasov with a Cameca MS-46 electron probe showed that the nonmetallic inclusions contained both deoxidizing elements, silicon, calcium, aluminum, and manganese, and elements found in the steel, vanadium, chromium, and iron.

In spite of the presence of deoxidizing elements in the nonmetallic inclusions, after heating to 1260-1300°C, soaking at that temperature, and slow cooling no evidence of devitrification into mineral phases characteristic of the slag was found in the specimens. It is reasonable to conclude therefore that the non-