"INTERNAL GETTERING"—METALLOTHERMIC REDUCTION PROCESSES IN THE EARLY STAGE OF SINTERING

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One of the aspects of modern material systems for high-strength sintered steel parts is the presence of alloying elements with widely different oxygen affinity. Compared with the base iron, the "new" alloying elements chromium, manganese, and silicon form oxides with much higher stability. It is shown here that, in the case of powder mixes, this leads to oxygen transfer from the base-iron particles to the alloying elements during the process of heating up to the sintering temperature, i.e., metallothermic reduction of the iron surfaces. Prealloyed-powder surface oxides, which are originally mostly iron oxide, are transformed into alloying-element oxides during heating, unless the iron oxides can be reduced at low temperature with hydrogen. In any case, the heterogeneity of the oxygen affinity is a parameter that has to be considered when defining alloying systems for sintered steels.

INTRODUCTION

The oxide-reduction process of the powder particles is one of the key factors for successful sintering of powder metallurgy (PM) steel products. Many studies show that in principle there are three stages of deoxidation of plain iron powders.[1] The first stage is mostly related to removal of adsorbed gases and physically and chemically adsorbed water on the surface of the powder; usually not hard to remove. Even after a dewaxing process at rather low temperatures the adsorbed species cannot be found anymore. The second stage is related to the removal of surface oxides, which is the crucial process for sintering. It is very important to note that the heating stage is extremely critical for the final properties of the material. Different furnace atmospheres result in different behavior of the powders. As an example, in inert atmospheres, the added carbon (graphite) is needed as a reducing agent, and reduction via the reaction $FeO + C \rightarrow Fe + CO$ leads to a sharp peak of mass 28 (CO) in the analysis of the sintering atmosphere near 700 °C. When sintering is performed in hydrogen, the reduction process occurs at much lower temperatures by hydrogen forming water vapor, which can be detected as mass 18 (H_2O) at around 420 °C, with only a little subsequent evolution of mass 28 (CO) at 850 °C (Figure 1). The third reduction peak, which represents the reduction of the internal oxides, is usually much broader, and it takes higher temperatures to reduce all the oxides that are located within the powder particles and the pressing contacts. This last reduction process is carried out in both cited atmospheres by carbon. The behavior can be easily explained by using the Gibbs free energy, usually shown in the Richardson-Ellingham diagram. This shows that the reduction potential of the hydrogen is rather high at low temperatures, while the reduction potential of carbon rises with temperature, leading to the described phenomena: the easily

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