Reaction Sintering of Cold-Extruded Elemental Powder Mixture Ti-48Al

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The influence of the extrusion ratio on sintering behavior of cold-extruded powder mixture Ti-48Al has been investigated. Both pressureless reaction sintering and hot isostatic pressing (HIP) without encapsulation were carried out. Moreover, two-step sintering, i.e., combination of pressureless sintering and HIP, was conducted. It was found that both porosity and pore size in reactively sintered specimens largely decrease with increasing extrusion ratio. For a given extrusion ratio, the porosity after pressureless sintering decreases with increasing temperature. Although a reduction of porosity can be reached by directly HIP specimens, the effect of applied pressure in case of combined treatments is strongly dependent on extrusion ratio. By applying an extremely high extrusion ratio of 350, material with a porosity of only 0.7 pct has been prepared by pressureless sintering and subsequent HIP without encapsulation while a reverse treatment route led to a porosity of 5%. On the contrary, lower porosities were obtained for low extrusion ratios of 17 and 25 by HIP and following pressureless sintering. The effect of extrusion ratio, as well as sintering temperature, was discussed. In addition, pore coalescing, gas penetration, and swelling were considered in order to understand the effect of applying pressure.

I. INTRODUCTION

TITANIUM aluminide alloys based on the intermetallic compound TiAl have become more interesting owing to their potential applications as high-temperature materials. These alloys exhibit low densities, high melting temperatures, good mechanical properties, and environmental resistance at elevated temperatures. They are mostly produced using ingot metallurgy. However, earlier work has shown that it is possible to prepare TiAl-based alloys by reactive powder metallurgy (RPM).[1,2]

In the RPM processing, the cold-extrusion technique is used to consolidate the elemental Ti- and Al-powder mixtures with or without additives. The as-extruded material exhibits no intermetallics and can therefore be easily machined to complex shapes, which are then reactively sintered to get the desired intermetallics. In this way, the poor workability of titanium aluminides can be evaded. During reaction sintering, more Al atoms move into Ti particles and lead to formation of pores if no pressure is applied. The final pore size is proportional to the size of Al regions. Normally, hot isostatic pressing (HIP) is applied to compress pores. An HIP treatment requires encapsulation of extruded pieces due to their open porosity and is therefore relatively expensive. It is thus of practical importance to reduce the size of Al regions and the open porosity of extruded pieces. This can be achieved by increasing the extrusion ratio $\varphi$, which is defined as the area ratio of the specimen cross sections before ($A_1$) and after extrusion ($A_2$). In this study, we report on the influence of the extrusion ratio $\varphi$ on porosity formation in Ti-48Al during both pressureless reaction sintering and HIP without encapsulation. Two-step sintering, i.e., combination of pressureless sintering and HIP, was also conducted.

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II. EXPERIMENTAL

Elemental titanium and aluminium powders of sizes smaller than 100 $\mu$m, with purities of 99.8 pct and 99.9 pct, respectively, were mixed in air to the desired composition Ti-48 at. pct Al. The powder mixture was uniaxially pressed at room temperature with 500 MPa to a green compact. This compact was cold extruded (at room temperature) using different extrusion ratios of $\varphi = 17$ and 25. A considerably higher extrusion ratio was obtained by bundling pieces of a previously extruded rod (Mueller et al.[3]) and by extruding the bundle again to give a total extrusion ratio of 350. Altogether, three extrusion ratios were applied in this study: $\varphi = 17$, 25, and 350.

The extruded specimens were reactively sintered under different conditions: in a vacuum ($=10^{-3}$ N/m$^2$) furnace for 6 hours at 600 °C, 1000 °C, and 1350 °C and in HIP equipment at 1350 °C/4 h/200 MPa. A heating rate of 20 °C/min was used in both cases. A combination of both pressureless sintering and HIP, i.e., first pressureless sintering and then HIP or vice versa, was also conducted.

As-extruded specimens as well as specimens reactively sintered under different conditions were examined using light microscopy (LM). A quantitative determination of the porosity, as well as the pore size distribution in the reactively sintered specimens, was carried out with the help of a computer-aided image analysis system. Polarized light was used to observe microstructural details, such as grain and phase boundaries. X-ray diffraction analysis was carried out to get information about phase formation.

III. RESULTS

A. Characterization of As-Extruded Conditions

Figure 1 shows the microstructures of the three as-extruded conditions with Al having a light and Ti a dark
Fig. 1 — LM photographs of as-extruded conditions with extrusion ratio of (a) and (b) 17, (c) and (d) 25, and (e) and (f) 350 in directions (a), (c), and (e) perpendicular and (b), (d), and (f) parallel to the extrusion direction.