11. Hot Forming of Ceramics

ROY W. RICE*
The Boeing Company
Seattle, Washington

ABSTRACT

This chapter discusses hot-consolidation of ceramic powders with and without additives, and hot working of ceramic bodies. Hot consolidation (e.g., by hot pressing) of powders without sintering additives is shown to generally produce the finest grain sizes. The resultant bodies generally have the highest strengths to several hundred degrees Kelvin. Additives such as LiF and NaF to oxides (e.g., MgO, CaO, and Al₂O₃) and of metals (molten at pressing) to carbides are shown to often aid consolidation and formability (e.g., allowing hot rolling). However, the use of such additives also often leads to some penalties such as greater grain growth or lower elevated temperature strengths. The major problem of hot consolidation of oxides, with or without additives, is shown to be removal of the last traces of impurities such as H₂O and CO₂, which are usually present in reacted form (e.g., hydroxides and carbonates), while other anion impurities may cause problems in carbides and borides.

Hot working (i.e., causing plastic deformation within grains) is discussed both for starting with solid bodies, and starting with powders where consolidation and working are done in the same operation. Neither method has yet produced bodies of as fine a grain size as can be achieved by hot pressing. However, elevated temperature strengths of some hot worked bodies are shown to be much greater than those achieved by hot pressing. These higher strengths result from hot working bodies with substantially reduced anion impurity levels, as well as obtaining both texturing and slower grain growth in the hot worked bodies. Other advantages (e.g., improved optical properties) may also be obtained by hot working.

Possible solutions to the problems of impurities left after consolidation and of reducing grain sizes of hot worked bodies are discussed. Obtaining powders with more controlled composition and finer particle and agglomerate sizes will help both problems. Some comments on the means of obtaining such powders are briefly outlined.

*Presently: Naval Research Laboratory, Washington, D.C.
Introduction

Hot forming of ceramics encompasses a variety of materials, methods, operations, and goals. Materials can be categorized as all or mostly glass, crystalline with some glass, or all-crystalline. The latter is clearly most pertinent to this volume and to the author's experience, and hence will be emphasized. However, some informative examples from the former two categories will also be presented. The crystalline materials discussed most will be the oxides, primarily the simple oxides such as MgO, CaO, and Al₂O₃, because they have been studied most. However, some results will also be given for carbides and borides.

Powder or solid bodies may be used without additives, or with glass or liquid-phase additions. The choice of these methods depends on whether the forming operation is hot pressing, hot rolling, normal forging, press forging, or hot extrusion. Both the method and operation depend on whether the goal is primarily consolidation, or primarily working. Both can be done at once, but then working is the major factor in determining operational parameters. Working will normally be hot working, that is, plastic deformation by slip or twinning processes at such a temperature that most of the lattice strain from the deformation is removed by recrystallization at the completion of the process. This requires more extreme parameters of temperature, pressure, and time.

The above comments listed only hot consolidation or working as goals because these are the primary goals. Shaping is also an important goal, but only in conjunction with consolidation or working. While substantial reduction in costs should be achieved, hot forming operations will generally be more expensive than more conventional forming operations of cold consolidation (pressing, slip casting, etc.) and sintering. Thus, if shape is the primary requirement and properties are secondary, hot forming will usually not be justified. However, where the superior properties achievable by hot forming are needed, then shaping in the hot forming operation can, of course, be an important benefit.

All of these methods and operations to achieve consolidation or hot working will be reviewed. A great deal of progress has been made, and more should be feasible. However, the quality of starting materials, especially powders, will be shown to be a major problem in further development, thus making this volume timely. (Some of the author's thoughts on powder preparation and processing will be briefly outlined in an appendix to this chapter.) Because of the scope of the subject and other pertinent reviews [1–6], this chapter will emphasize recent developments and aspects not emphasized previously. In particular, some of the established or emerging problems of the various techniques will be emphasized, especially in the more established or conventional hot forming methods.