Chapter 3
Ultra High Temperature Ceramics: Processing, Properties, and Applications

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ABSTRACT

Most engineering applications concerned with exposure to extremely high temperatures, (>2000°C), and harsh environmental conditions require the use of ceramic materials possessing melting points in excess of ~ 3000°C. Such ceramics, more commonly referred to as ultra high temperature ceramics (UHTCs), are required to possess a desired combination of mechanical and physical properties, which are retained despite the extremely high temperatures as demanded by their applications. However, there are some drawbacks of such materials, with respect to both their processing as well as their properties, which limit their applications to a considerable extent and demand careful engineering of their composition and microstructure to circumvent those limitations. Continuing research efforts have been focused on addressing such issues. Against this backdrop, the present review summarizes the various properties possessed by the UHTCs and critically analyzes the issues concerned with such materials. Through such analysis, an overview of

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the more recent research efforts that have been conducted to solve the various 
issues related to this material class is presented. This also highlights the difficulties 
associated with experimental assessments of the various properties of such materi-
als. Lastly, the various existing applications and potential future applications for 
such materials are mentioned, with an outlook towards the issues that need to be 
addressed in the near future.

INTRODUCTION

Ceramics with melting points in excess of 3000°C are usually classified as ultra 
high temperature ceramics (UHTCs) (Cutler, 1991; Telle, 1994; Cotton, 2010; Basu, 
2006; Clougherty, 1968; Wuchina, 2007; Bellosi, 2006). The applications of UHTCs 
are extensive, which range from more conventional applications, like in process 
metallurgy or chemical plants, to more advanced applications such as in hypersonic 
vehicles. A very important feature of the UHTCs is that not only do they possess 
excellent mechanical properties (such as hardness, strength) and thermophysical 
properties at room temperature, but also such properties can be maintained at elevated 
temperatures. Due to their refractoriness, these materials also possess appreciable 
creep resistance. Hence UHTCs are amongst the few material classes that are suitable 
for various structural applications demanding constant exposure to extremely high 
temperatures, sometimes in excess of ~ 2500°C. Most of the ultra high temperature 
structural applications are also associated with corrosive environment and even 
highly aggressive environments. Hence, resistances against oxidation, corrosion and 
thermal shock are also some of the pre-requisites for use at such high temperatures, 
which are satisfied by the UHTCs. In addition to such beneficial thermomechani-
cal and thermochemical properties of the ultra-high temperature ceramics, their 
attractive physical properties such as lower densities and low coefficient of thermal 
expansion are advantageous when compared to the refractory metals (such as W, 
Mo, Ir). This combination of properties makes UHTCs an ideal class of materials 
for applications in air/space-borne structures that are amongst the most important 
ultra-high-temperature applications, demanding a higher property-to-weight ratio.

In most cases, the materials characterized by such unique combination of prop-
erties are covalently bonded ceramics (Cutler, 1991; Telle, 1994; Cotton, 2010). More 
precisely, mainly the borides (Cutler, 1991; Telle, 1994; Basu, 2006; Fahrenholtz, 
2007; Murthy, 2006; Gasch, 2004; Tang, 2007; Mukhopadhyay, 2008; Mukhopad-
hyay, 2009; Raju, 2008; Raju, 2009; Levinea, 2002; Chamberlain, 2004; Ferber, 
1983; Kang, 2001; Kang, 1989; Einarsrud, 1997; Biswas, 2006; Torizuka, 1996; 
Torizuka, 1992; Murata, 1967; Bellosi, 2006; Monteverde, 2005; Sayir, 2004; Blum, 
2004; Savino, 2008; Upadhya, 1997; Marschall, 2004; Gasch, 2004; Pierson, 1996)
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