Chapter 11
Reactive Melt Infiltration of Carbon Fiber Reinforced Ceramic Composites for Ultra–High Temperature Applications

Bai Shuxin
National University of Defense Technology, China

Ye Yicong
National University of Defense Technology, China

Tong Yonggang
National University of Defense Technology, China

Zhang Hong
National University of Defense Technology, China

ABSTRACT

Carbon fiber reinforced ultra high temperature ceramic matrix composite (C/UHTC) is one of the most promising structural materials capable of prolonged operation in oxidizing environment at ultra high temperatures above 2000 °C. Reactive melt infiltration (RMI) is a viable processing choice for C/UHTC composite. Compared with chemical vapor infiltration (CVI) and polymer impregnation and pyrolysis (PIP), RMI does not suffer from the drawbacks of time-consuming and high cost. It is viewed as a promising means of achieving near-net shape manufacturing with
Reactive Melt Infiltration of Carbon Fiber Reinforced Ceramic Composites

INTRODUCTION

Ultra-high temperature ceramics (UHTCs) are the most promising materials that could be used in oxidizing environments at temperatures over 2000°C. The most widely studied UHTCs are refractory borides and carbides, such as ZrB$_2$, HfB$_2$, ZrC, HfC, TaC and TiC. These materials have been considered to have a great potential to use in thermal protection systems and propulsion systems for hypersonic flight vehicles or reentry vehicles, owing to their unique properties (shown in Table 1 [Justin et al., 2011]) of high melting point, high hardness and excellent corrosion resistance (Tripp et al., 1973; Hinze et al., 1975; Han et al., 2008). A number of government facilities, as well as universities, have devoted to the research of UHTCs. HfC, ZrC, ZrB$_2$, and HfB$_2$ are the mostly studied UHTCs, which are considered to be potential candidate for sharp leading edge and some other high temperature ablation-resistant components (Kolodziej et al., 1997). During the past years, numerous of work has been focused on the material design (Monteverde et al., 2002; Opeka et al., 2004), densification (Zhang et al., 2002; Qu et al., 2008) and property evaluation of these materials (Levine et al., 2002) and great achievements have been received.

In spite of the high strength and excellent ablation resistance, these ceramics are brittle and display little to no plasticity within a broad temperature range, which limits their widespread applications. Great efforts including grain size control, additives, grain boundary purification and some novel sintering methods have been made to improve the fracture toughness of these ceramics (Johnson et al., 2009; quick processing time and at low cost. Recently, great efforts have been made on RMI process for C/UHTC composite. Carbon fiber reinforced ZrC, HfC and TiC composites have been successfully fabricated by RMI. The aim of the following chapter is to introduce the RMI process and summarize the progress in RMI process for C/UHTC composite. In addition, future research directions of RMI are also proposed.

Table 1. Properties of some ultra high temperature ceramics form (Justin et al., 2011)

<table>
<thead>
<tr>
<th>Material</th>
<th>Crystal Structure</th>
<th>Density (g/cm$^3$)</th>
<th>Melting Point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HfC</td>
<td>Face-centered cubic</td>
<td>12.76</td>
<td>3900</td>
</tr>
<tr>
<td>ZrC</td>
<td>Face-centered cubic</td>
<td>6.56</td>
<td>3400</td>
</tr>
<tr>
<td>HfB$_2$</td>
<td>Hexagonal</td>
<td>11.2</td>
<td>3380</td>
</tr>
<tr>
<td>ZrB$_2$</td>
<td>Hexagonal</td>
<td>6.1</td>
<td>3245</td>
</tr>
<tr>
<td>TiC</td>
<td>Cubic</td>
<td>4.94</td>
<td>3100</td>
</tr>
<tr>
<td>TaC</td>
<td>Cubic</td>
<td>14.50</td>
<td>3800</td>
</tr>
</tbody>
</table>
Optimization of WEDM Process Parameters for MRR and Surface Roughness using Taguchi-Based Grey Relational Analysis