CVI manufacturing routes of non-oxide CMCs

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Aims of this Presentation

• Introduction to ATL
• Outline the basics of the CVI process
  • What is it?
  • What can it be used for?
• Discuss some methods of using CVI for the creation of non-oxide CMC materials
  • How is this done?
  • What are the benefits?
  • What considerations have to be made?
Innovative solutions to your coating challenges

Research ● Production ● Design ● Equipment ● Support
Innovative solutions to your coating challenges

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Research • Production • Design • Equipment • Support
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Innovative solutions to your coating challenges

- Turnkey Coating Equipment
- Equipment Design
- Low Volume Production
What is CVI?

There are multiple different forms defined mostly by:
- Heating method (resistive, microwaves, induction etc)
- Operating pressures (atmospheric, high vacuum)
- Reagent materials (solids, liquids, gases)

CVI is the same as CVD, but targeting infiltration of a porous substrate to achieve coatings or to densify that substrate
- It is achieved by slowing down the reactions achieved in CVD
- For this purpose, it tends to be done at lower temperatures and pressures
  - Low and slow like American BBQ

Chemical Vapour Deposition
“A process where gaseous precursors react to form a solid coating on a heated substrate”
CVI Example: BN and SiC

\[ \text{BCl}_3(g) + \text{NH}_3 \rightarrow \text{BN} + 3\text{HCl}(g) \]

\[ \text{CH}_3\text{SiCl}_3(g) \xrightarrow{\text{H}_2} \text{SiC}(s) + 3\text{HCl}(g) \]

- An example system, typical for aerospace applications
- Further densification can be done by CVI or alternative routes, but it first needs a protective coating
### CVI – Materials and Applications

<table>
<thead>
<tr>
<th>Interphase</th>
<th>Protective Coatings</th>
<th>Exterior Coatings</th>
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</thead>
<tbody>
<tr>
<td>BN</td>
<td>SiC</td>
<td>SiC</td>
</tr>
<tr>
<td>Si-BN</td>
<td>Si$_3$N$_4$</td>
<td>UHTCs (e.g. ZrB$_2$)</td>
</tr>
<tr>
<td>Carbon</td>
<td></td>
<td>Oxides</td>
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<tr>
<td>Oxides</td>
<td></td>
<td>EBCs (e.g. disilicates)</td>
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Plus, many other elements and compounds possible.
Interphases by CVI

- Non-line of sight process, so shaped preforms are possible
- BN, Si-BN, C and oxides
- Multilayers also possible
SiC Densification by CVI

- SiC CVI is an option for full densification
- Higher cost processing, but purer coatings
SiC CVI is an option for full densification
Higher cost processing, but purer coatings
ZrB$_2$, Yttria and Ta on SiC/SiC shown as examples, but other options are possible:
Oxides
Thick SiC
Metal carbides, nitrides and borides
CVI’s role in CMC Manufacture

Existing Batch Process

Coating stacks of fabric all at once, and forming the shape of the component

Continuous Process

Coating fibre directly, then forming into the shape afterwards
Positives

- Complicated shape formation can be done with the uncoated fabric/fibre
- Stiffening of shape can happen in the same step
- Flexible process, easy to apply multilayers and change target thicknesses

Challenges

- Uniformity of the interphase coating is not perfect, the larger and more complicated shapes make it worse
- Engineering of suitable moulds for complex shapes including hollow sections
- New shape, new mould
Why Continuous?

**Positives**
- Uniformity of the interphase coating much improved versus the batch process
- Ability to tailor specific interphases to specific regions of composites
- Changes to design of component simpler
- Less wastage of high value materials

**Challenges**
- Equipment design less flexible
- Handling of coated fibres may limit the shapes that can be formed with it
- Tight control not always necessary, so could be more expensive
Applications beyond transportation are also moving towards CMC materials
CEM-WAVE is a collaborative project with European partners to develop shaped tubes from CMCs
CVI will be used to create shaped tube components, and also join tubes together to make the complex pipe shape required
The dielectric properties of CMCs will enable these tubes to have their performances monitored during service as radiant tube furnaces
Work done using microwave CVI techniques in collaboration with the University of Pisa and the University of Birmingham
<table>
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<th>Conventional Heating</th>
<th>Microwave Heating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positives</td>
<td>• Simple to set up&lt;br&gt;• Good for complex shapes</td>
<td>• Reverse temperature gradient encourages coating from inside outwards&lt;br&gt;• Faster heating and processing, lowering costs</td>
</tr>
<tr>
<td>Challenges</td>
<td>• Coating on all hot surfaces&lt;br&gt;• Coating can block pores and prevent further infiltration</td>
<td>• Achieving heating uniformity, especially on shaped components</td>
</tr>
</tbody>
</table>
UK Fusion Challenge

- Project to develop oxide external and interphase coatings for CMC components in fusion reactor tritium breeder blanket modules
  - Employs an aerosol MOCVD route developed at ATL
- Aim to prevent corrosion vs liquid Li, and work as tritium permeation barriers
- UKAEA and Oxford University partners
- Builds on work with complex shaped tube CMC components
- May have spin-off for other applications
CVI and CVD can both be used at different stages of the process in the manufacture of non-oxide CMC materials of various types for several applications.

Thorough understanding of the full picture is needed at every stage of the design and creation components to delivery the greatest result:

- Design needs to understand the intended manufacturing pathway
- The process selected needs to understand the end application, and feed back into the design