memorandum 627

SOME REMARKS ON OPTIMIZING
PRODUCTION CYCLE TIMES
FOR CFRTP PRODUCTS.

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Some remarks on optimizing production cycle times.

In general the processing of continuous fiber reinforced thermoplastic composites can be described as follows:

\[
\text{impregnation} \quad \text{consolidation} \quad \text{forming}
\]

\[
\text{raw material} \downarrow \text{prepreg} \downarrow \text{laminate} \downarrow \text{product}
\]

From processing point of view this sequence of events can be shown in a \( p, t, T \) (pressure, time and temperature) diagram:

The purpose of the different phases is obvious. The end result of phase II, a 100% consolidated sheet material can be obtained in a lot of ways. Equipment to perform the consolidation phase can vary from a set of hot and cold calendar rollers up to a moving belt press. In any case an adequate combination of pressure, time and temperature \( p, t, T \) has to be generated.
CONSOLIDATION.

A specific combination of p,t,T cannot be described for any particular thermoplastic matrix material, because this will depend on factors like the viscosity of the hot matrix material, the degree of impregnation/consolidation of the prepreg material and from economical point of view: available equipment, available processing time and so on.

However, with regard to industrial use of these materials some remarks concerning consolidation parameters can be made. The time needed to obtain a 100% degree of consolidation for a typical combination of pressure and temperature is strongly depending on the viscosity of the hot matrix material:

For instance, from experience it can be stated:

<table>
<thead>
<tr>
<th>matrix</th>
<th>remarks</th>
<th>cons. time (typical)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEI</td>
<td>solution impregnation (Ten Cate)</td>
<td>20 to 30 min</td>
</tr>
<tr>
<td>PA</td>
<td>filmstacking</td>
<td>15 to 20 min</td>
</tr>
<tr>
<td>PA</td>
<td>FIT weave (Porcher)</td>
<td>5 to 10 min</td>
</tr>
<tr>
<td>PET</td>
<td>Comingled weave (DSM)</td>
<td>&lt;1 to 5 min</td>
</tr>
</tbody>
</table>

As can be seen, a PET/fabric combination, (but also PA, PP and other low viscous plastics) do offer possibilities for fast consolidation processes (and also advantages with respect to forming products, mould filling and so on). This is especially interesting for industries where fast production time and low material costs are important.

For the matter of low viscosity, this is the keyword in research conducted by the chemical industries (GE, ICI) on high performance thermoplastics. On the other hand, 'low performance' plastics do match the second mentioned issue: low material costs. Again, all this is a matter of strategy.
FORMING.

Considering the forming phase (III), two different options are available for a manufacturer of CFRTP products depending on his strategy:

- purchase prepregs for in house consolidation and forming:
  relative low material costs - high production costs
- purchase consolidated sheet material for forming:
  High material costs - relative low production costs

The characteristics of the second option are clear and the research activities can be focused on the forming techniques only.

The first option, however, offers promising possibilities to the manufacturer to create his own consolidation/forming process. For instance, depending on the time needed for 100% consolidation it can be considered skipping the cooling between consolidation and forming to minimize costs (operating-, overhead and stocking).

As an example, an 'in situ measured' time-temperature diagram for the production of a hat profile from PET/glass fabric (a weave of co mingled yarns) is shown below:

![T-t relation during rubber forming a profile of Glass/PET hybrid yarn (weave, unconsolidated)](image-url)
At point '0' the material existed of weaves of co mingled fibers stacked to obtain a thickness of about 1 mm. At point '6' a hat profile was formed and cooled down for further handling. It is obvious that adjusting a strategy at this point will be eased by short consolidation times, thus by the existence of low-viscous matrix materials like PET, PA, ABS and PP.

PARTIAL CONSOLIDATION.

Furthermore, if a pressing phase is incorporated in the production process (for example rubber forming) and if the consolidation time is really short it can even be considered to use the heating phase to obtain a (arbitrarily stated) 60% degree of consolidation while the remaining 40% is being obtained during the pressing phase of the rubber forming cycle. Preliminary experiments using a PET/fabric combination revealed that the above mentioned method is possible.

Considering a partial consolidation during heating and the remainder to be obtained during pressing a production rate per mould is obtained as shown in the figure below:
As can be seen production times per mould can be as low as 12 seconds per product. Note that the heating has been carried out using conduction in the hot platen press. It depends on the characteristics of the material (and of the heating system) whether it needs to be buffered in the heating device prior to forming.

Investigations on this field are ongoing.