Steam-sterilization: Fatal for both germ and polymer
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Introduction
Polycarbonate (PC) is often used in medical applications, because it combines attractive mechanical properties and transparency with good resistance to sterilization.

Figure 1: Polycarbonate is widely used in medical applications.

However, the mechanical properties of PC deteriorate rather quickly when it is repeatedly steam-sterilized; it becomes brittle and easily breaks. Fig. 2a shows a clear transition from ductile (yield) to brittle (break) failure as the number of steam-sterilization cycles increases.

Figure 2: Failure stress of three steam-sterilized PC grades, having different molecular weights (MW). (a) linear (b) logarithmic

Three phenomena have been proposed to be the cause of this embrittlement; these are now discussed separately.

1. Cavity formation
Upon steam-sterilization, disk-like cavities (~1 mm) are formed (Fig. 4a) as a result of the water supersaturation that occurs during cooling. These cavities act as crack initiation sites (Fig. 4b), but are not the sole cause of the embrittlement because they also appear in ductile PC.

Figure 3: (a) Cavities appear in PC samples upon steam-sterilization. (b) Cracks may initiate from these cavities when stress is applied.

2. Hydrolysis
Hydrolysis is a chemical reaction between PC and water that leads to a reduction in molecular weight. Experiments on repeatedly cycled PC samples show that such reductions are small (see Table 1) and can therefore not be responsible for the observed embrittlement.

<table>
<thead>
<tr>
<th># of cycles</th>
<th>0</th>
<th>7</th>
<th>14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low MW</td>
<td>15.9</td>
<td>15.6</td>
<td></td>
</tr>
<tr>
<td>Medium MW</td>
<td>24.6</td>
<td>23.8</td>
<td>23.0</td>
</tr>
<tr>
<td>High MW</td>
<td>28.6</td>
<td>28.4</td>
<td>28.1</td>
</tr>
</tbody>
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Table 1: Molecular weight results (in kg/mol) obtained from SEC measurements.

3. Physical aging
Aging increases the yield stress of PC over time, eventually causing a ductile-brittle transition (Fig. 5a). This aging-induced yield stress evolution is described well by Klompen et al.1 (Fig. 5b). Their model also accurately predicts the increase of yield stress upon steam-sterilization until PC becomes brittle (Fig. 2b). Combining Figs. 5a and 5b shows that aging causes PC to become brittle at a (MW-determined) critical yield stress.

Figure 4: Influence of temperature-accelerated aging (annealing) on mechanical properties of PC. (a) embrittlement 2 (b) change in yield stress

Conclusion
Physical aging is the dominant factor in the embrittlement of PC that occurs upon steam-sterilization. Aging makes PC more susceptible to brittle failure and, therefore, more sensitive to flaws in the material. Such flaws exist in large quantities due to the formation of cavities.