STRENGTH AND SURFACE MORPHOLOGY OF UHMWPE FIBERS EXTRACTED FROM FATIGUED POLYETHYLENE BASED COMPOSITES

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**Introduction**

**Materials**
- Consolidated Sheets
  - Each sheet consists of Polyethylene fibers unidirectional 0-90 cross plies.
  - Two types of consolidated panels were evaluated:
    - Baseline Sheet - 0 cycles
    - Fatigued Sheet - 11,160 cycles at RT and at -20°C

**Objectives**
- To quantify the strength of fibers extracted from fatigued consolidated sheets.
- To identify the failure modes/damages appeared on the fiber surface before and after cyclic fatigue loading.

**Problem Specification**
- Successfully demonstrate filament extraction without causing damage to the fibers.
- Specify types of damage/failure mode on microscales caused by cyclic fatigue loading on the consolidated fibers at RT and at -20°C.
- Correlate the failure modes / damage to strength degradation.

**Cyclic Fatigue Procedure**
- A specially developed fatigue setup was utilized along with an environmental chamber.
- The consolidated sample was folded at midplane, then mounted in the cyclic fatigue setup.
- Consolidated samples were exposed to cyclic fatigue loadings for 8hrs (11,160 cycles) at RT and at -20°C.
- The cross plies were extracted from the fibers in order to get samples to run fatigue testing.

**Methodology**
- A high-resolution camera (100 MP camera) was used to measure crease dimensions induced by fatigue.
- SEM microscopy was conducted to determine failure modes in the filament due to fatigue.
- Develop a method to remove resin matrix and extract individual filaments

**Fiber Extraction Process**
- Remove a strip of fibers from a single layer of the sheet pack
- Soak in THF for 24 hours
- Periodic agitation and rinsing
- Perform solvent exchange every 1-2 hours
- Remove fibers from solvent to dry

**Tensile Testing**
- Fiber wrapped around the capstan.
- Tensile testing was conducted on fibers (from baseline and fatigued sheets) at gauge length of 25 mm and 5 mm/min cross-head speed.
- The Fatigued /folded region was always at the middle of the gauge length of the sample during tensile loading.
- Prior tensile testing, each fiber diameter was measured.

**Results and Discussion**

**Strength-Displacement Behavior**
- Fibers exhibited a strength ranging from 3.8 to 4.0 GPa after fatigue at RT for 8hrs. For fibers fatigued at -20°C, the strength ranges from 2.7 to 3.7 GPa.

**Images of Fatigued Surfaces**
- Prior fatigue @ RT
  - Fibers exhibit kink band spacing on average 69±37 μm
  - Vertical crease show 15μm in length and ~1.4 in width.

- After cyclic fatigue @ RT for 8hrs
  - Fibers exhibit kink band spacing on average 50±21 μm
  - Vertical crease show 20μm in length and ~1.4 in width.

- Prior fatigue @ -20°C
  - Fibers exhibit kink band spacing on average 61±29 μm
  - Vertical crease show 8μm in length and ~1.4 in width.

- After cyclic fatigue @ -20°C for 8hrs
  - Fibers exhibit kink band spacing on average 61±29 μm
  - Vertical crease show 8μm in length and ~1.4 in width.

**Failure Probability Distributions**
- With respect to unfatigued fibers, prior fatigued and fatigued fibers at RT for 8hrs exhibit shifts to lower strength levels for failure probability above 25%.
- With respect to unfatigued fibers, the shifts to lower strength levels obtained from cold fatigued fibers are significantly higher than those obtained from unfatigued fibers.

**Average strength and kink band spacing**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean (MPa)</th>
<th>Standard Deviation</th>
<th>Average kink band spacing(μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unfatigued HW fibers (baseline)</td>
<td>4.80±1.00</td>
<td>0</td>
<td>200 ±100</td>
</tr>
<tr>
<td>Prior RT fatigue</td>
<td>4.19±0.97</td>
<td>13%</td>
<td>65±28</td>
</tr>
<tr>
<td>After RT fatigue for 8hrs</td>
<td>4.71±0.84</td>
<td>17%</td>
<td>60±25</td>
</tr>
<tr>
<td>Prior cold fatigue</td>
<td>4.64±0.56</td>
<td>7%</td>
<td>66±20</td>
</tr>
<tr>
<td>After cold fatigue for 8hrs</td>
<td>4.7±0.87</td>
<td>25%</td>
<td>65±20</td>
</tr>
</tbody>
</table>

**Summary and Conclusion**
- Cyclic fatigue at RT and -20°C reduced the dimensions (length and width) of the creases appeared on surface of the fatigued samples.
- Cyclic fatigue induces damage in the form of kink bands and fiber splitting.
- Strength degradation caused by cold fatigue is larger than that obtained for the fibers after fatigue at RT for 8hrs.

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