Development of Laboratory Tests for the Physical Durability of LLINs

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How Textile Structure Influences Durability

- LLINs are made by warp knitting.
- Yarns oriented lengthwise through the fabric.
  - Analogous to “grain” in wood.
- Strength and tearing properties are directional.
  - Tears tend to run parallel to yarn orientation.
Current LLIN Yarn Patterns

Polyester and Polypropylene (multifilament yarns)

Polyethylene (monofilament yarns)
Raveling

- Severing one or more yarns can lead to a process of sequential loop disengagement.
  - Small holes get larger.
  - Hole enlargement occurs in one direction.
  - No additional fiber breaks.

process of raveling after a single yarn cut
Typical LLIN Damage

- Oval holes
- "Ladders" caused by raveling
- Yarn orientation
Hypothetical Deterioration Pathways

- No Holes
- Large Holes and Tears
- Small Holes
- Raveling
- Yarn Break
- Yarn Break, Cut, and/or Melt

Intact Net

- Damaged Net

- Large Holes and Tears
- Raveling
- Yarn Break

Yarn Break, Cut, and/or Melt
Potentially Useful Tests

- Susceptibility to initial hole formation.
  - Snagging (tensile breaks)
  - Cutting
  - Melting
- Strength loss after hole formation.
- Resistance to raveling.
### NETS INVESTIGATED

<table>
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<tr>
<th>NET</th>
<th>YARN</th>
<th>POLYMER</th>
<th>FILAMENT</th>
<th>DENIER</th>
<th>WEIGHT (g/m²)</th>
<th>KNITTING PATTERN</th>
<th>UNIT CELL</th>
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<tr>
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**Pattern A**

**Pattern B**

**Pattern C**

**Pattern D**

(Images of patterns are shown)
Resistance to tearing by snagging 
(Skovmand and Bosselmann, 2011)

Resistance to tearing by snagging (CDC/NCState)

DuraNet and Olyset are best performers in this test.
Strength loss after yarn severing

Polyester/Polypropylene nets perform best in this test.
**Raveling resistance**

- **Martindale Abrasion Tester**

  - Top platen Oscillates Specimen uncut
  - Bottom platen Stationary Specimen cut

  Side view of test platens showing net specimens in place.

  Specimen showing enlarged hole due to raveling.

  Hole growth in 12 cut Olyset samples

  Cut A in **RED**; Cut B in **BLUE**

- Only Olyset Nets showed tendency to ravel in this test.

- Rate of hole enlargement was inconsistent.

- Further test development is needed.
Consequences

- Hole formation and enlargement likely involves *multiple mechanisms*.
- It’s unlikely that a single test will be able to predict durability. Instead, a *combination of tests* will be needed.
  - Net performance depends on the conditions the net is exposed to.
- Nets will get holes: designing more durable LLINs should focus on *resisting hole enlargement*.
- Users should be encouraged to *repair even small holes* and not wait for holes to get large.
- *Correlation with field results* is needed.