RECLAMING VALUE FROM ULTRA HIGH MOLECULAR WEIGHT POLYETHYLENE WASTE FIBRES

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Agenda

- Ultra High Molecular Weight Polyethylene (UHMW-PE)
- UHMW-PE fibre applications
- UHMW-PE waste fibre
- Material and fibre characterisation
- Ring-spun yarn production
- Yarn characterisation
- Plasma treatment on fibres
- On-going and future research activities
- Conclusion
Ultra High Molecular Weight Polyethylene (UHMW-PE)

- Linear high-density poly(ethylene) synthesised from monomers of ethylene.
- **UHMW-PE fibres** are typically produced by a *gel-spinning process* that spun and draw the UHMWPE molecules into highly crystalline fibres with more than 95% of the molecules oriented in the fibre direction.
  - **High tenacity** (up to 7 GPa)
  - **High elastic modulus** (up to 230 GPa)
  - **Low density** (0.970 g/cm³)

Fibre characterised by an exceptional strength, modulus and abrasion resistance
UHMW-PE fibre applications

- UHMW-PE fibres used in high-demanding sectors: military, fishing, shipping, metalworking, medical, offshore industries, protective apparel, vehicle armouring, etc.

MARKET DEMAND

PRODUCTION VOLUME

WASTE

200 tons/year

Oil-based
Non-biodegradable
The Waste Hierarchy

- European Societal Challenge “Climate action, environment, resource efficiency and raw materials”

**AIM OF THE RESEARCH PROJECT:** developing innovative yarns using recycled UHMW-PE fibres
Material and fibre characterisation

- Recycled Dyneema® fibres supplied by an European company, mechanically and chemically recovered from Dyneema® scraps.

- Tensile tests DIN EN ISO 5079:1995 - Vibrodyn 400 Lenzing instrument at standard atmospheric conditions (20±2°C; 65%±2% RH) - Gauge length 20 mm, crosshead speed 60 mm/min
- Denier of the fibres ISO 1973:1995 - Vibroskop 400 Lenzing instrument at standard atmospheric conditions (20±2°C; 65%±2% RH)
- rDf length and length distribution - Spinlab Fibrograph 530 (fibrographic analysis)
- Scanning Electron Microscope (SEM) (ZEISS EV040)
Fibre characterisation

<table>
<thead>
<tr>
<th>Properties</th>
<th>Recycled fibres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average fibre length (mm)</td>
<td>39</td>
</tr>
<tr>
<td>Max fibre length (mm)</td>
<td>110</td>
</tr>
<tr>
<td>Min fibre length (mm)</td>
<td>&lt; 10</td>
</tr>
<tr>
<td>Fibre diameter (μm)</td>
<td>40.93</td>
</tr>
<tr>
<td>Linear density (dtex)</td>
<td>10.32</td>
</tr>
<tr>
<td>Linear density C.V. (%)</td>
<td>11.24</td>
</tr>
<tr>
<td>Tenacity (cN/dtex)</td>
<td>12.22</td>
</tr>
<tr>
<td>Tenacity C.V. (%)</td>
<td>14.22</td>
</tr>
<tr>
<td>Elongation at break (%)</td>
<td>10.13</td>
</tr>
<tr>
<td>Elongation at break C.V. (%)</td>
<td>6.3</td>
</tr>
</tbody>
</table>
Ring-spun yarn production

- rDfs have a poor adhesion property with a low friction coefficient, making gripping difficult during the process of carding.
- rDfs were blended with virgin modacrylic fibres (MAfs) (40 mm length; 12 dtex fineness) to 60:40 weight ratios by weight.

The fibrous material transits through a pair of feed cylinders (1), which pinch the blanket being input and pass it to a licker-in cylinder (2), working synergistically with a doffing cylinder (3), the latter preferably placed below the licker-in cylinder (2) and at a distance therefrom dictated by the specific production needs. The doffing cylinder (3) has the task of parallelizing and adjusting the fibrous mass brought onto the licker-in cylinder (2). A drum (4) rotates clockwise and has clothing points (with a special profile ensuring maximum holding of the fibres) tilted in the same sense of the motion. A carding segment (5) has the purpose of parallelizing the fibres even more, reducing their mass, uniformly distributing them on the drum (4), thereby facilitating the task of the actual carding. The carding action, enabling the feed and the partial parallelizing of the fibres, is increasingly ensured by the further carding sectors (6), (8), (10) and (12). Between two consecutive carding sectors there is an open slits (7), (9), (11) able to separate the fraction of short fibres (or broken fibres) and the dust generated during the carding step, which would prove damaging for the subsequent processing. A suction system guarantees the removal of these particles, making more compact and even the materials on the drum. Another carding system (13), analogous to (5) but with a clothing with thinner and thicker-populated points, set at the outlet of the drum (4), enables a further parallelizing of the fibres. As to fibre transit, fibres held on the clothing of the clockwise-rotating drum (4) pass on a doffer cylinder (14). When being output from the device (15), the semi-finished product is in the form of a web. The web receives a new parallelizing by a drawing system (16), and become a sliver.
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Yarn characterisation

<table>
<thead>
<tr>
<th>Properties</th>
<th>Yarn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Count (Nec)</td>
<td>7.0</td>
</tr>
<tr>
<td>C.V. Count (%)</td>
<td>1.30</td>
</tr>
<tr>
<td>Twist yarn (turns/metre)</td>
<td>394</td>
</tr>
<tr>
<td>Tenacity (cN/tex)</td>
<td>13.20</td>
</tr>
<tr>
<td>Average Elongation (%)</td>
<td>10.60</td>
</tr>
<tr>
<td>Irregularity (U%)</td>
<td>23.96</td>
</tr>
<tr>
<td>Thin Places</td>
<td>3093,00</td>
</tr>
<tr>
<td>Thick Places</td>
<td>2152,00</td>
</tr>
<tr>
<td>Hairiness (H)</td>
<td>8.69</td>
</tr>
</tbody>
</table>

Yarn with remarkable visual effect that could be used in a number of applications, such as interior and exterior textiles for household and public applications (museums, cinemas, churches, offices, congress centres, schools, means of transportation, etc.), including curtains, carpets, sofa, chairs, seats, bed covers, flags, banners, and similar, where Dyneema® and modacrylic fibre’s properties (i.e., lightness, soft hand, fair abrasion, pilling and wrinkle resistance, excellent resistance to chemical agents and sunlight, flame resistant, and high tenacity) are requested.

Fair tenacity

High linear density irregularity due to high fibre length irregularity (difficulties in ring drawing steps)

→ SLUB YARN

USTER Tensorapid strength measurement system at standard atmospheric conditions (20±2°C; 65%±2% RH) - ISO 11566:1990.
Plasma treatment on fibres

- Recycled Dyneema fibres are chemically inert and the bonding strength to other materials, like resins, is weak.
- Moreover, the coefficient of friction is very low, so the fibre is extremely slippery.
- In order to improve current characteristics and performance of the recycled fibres, and to impart certain desired properties (such as wettability, adhesion, surface energy, printability, dyebility, etc.) without altering bulk properties, atmospheric plasma treatments have been tested on rDfs.
- Different chemical groups have been grafted on the surface, using a wide choice of functionalizing agents (i.e., siloxanes, amines, carboxylic acids), and the ageing has been tested during a two months period. To evaluate type and concentration of newly expressed functional groups, X-ray Photoelectron Spectroscopy (XPS) analysis has been conducted on rDfs samples.
Plasma treatment on fibres

Higher oxygen concentration (mix A – oxygen containing precursor) or nitrogen concentration (mix B) in comparison to untreated fibres.

<table>
<thead>
<tr>
<th>Sample</th>
<th>C</th>
<th>O</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-treated</td>
<td>91.3%</td>
<td>5.9%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Mix A</td>
<td>88.5%</td>
<td>10.5%</td>
<td>1.8%</td>
</tr>
<tr>
<td>Mix B</td>
<td>76.7%</td>
<td>19.5%</td>
<td>620%</td>
</tr>
</tbody>
</table>

Enhanced hydrophilicity and reactivity, fundamental for further dyeing and printing processes.

by chain scission or Low Molecular Weight Oxidized Materials (LMWOM)) -> formation of nano-roughness on fibre surface.
On-going and future research activities

- Light-fastness, dyeability, printability and flame-retardant tests on the rD/MA yarn.
- rDfs treated with atmospheric plasma will be blended with modacrylic fibres and then spun into a yarn that will be fully characterised for measuring improvements in chemical/physical/mechanical properties.
- Blending rDfs with other fibres (natural, man-made and inorganic).
Conclusion

- UHMW-PE waste fibres still have a high value (technical characteristics and economic value)
- Current waste management solutions (landfilling and energy recovery) are not satisfactory.
- Novel solution: recycling.
- AIM: developing innovative yarns using recycled UHMW-PE fibres.
- RESULTS: slub yarn that could be used in a number of applications, such as interior and exterior textiles for household and public applications.
- Atmospheric plasma treatment improves fibres’ and yarn’s performance → wider application domain.
Thank you for your kind attention!

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