Appendix
Exploring circular possibilities for using End-of-Use Dyneema® from the commercial marine market

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Appendix A

The most used properties of Dyneema® fiber was found by analysis which Dyneema® property is used in different applications. All the applications come from the DSM Dyneema® website, **(DSM, 2018 II)** This analysis is done to get an idea of what the valuable properties of Dyneema® are.

Cargo nets Air France

By using Dyneema® cargo net from Dyneema® fuel and emissions could be saved. The high strength for low weight was used to create these savings. As secondary property abrasion resistance increased the durability of the nets compared to polyester cargo nets.

Deepwater installation cables

The weight of the steel itself limits the lifting capabilities of the Vessel. Dyneema® is a lot lighter and therefore allows deeper lifting projects. The property that Dyneema® is a light for its strength is used.

Seismic ropes

Provide benefits over traditional solutions. The higher strength per weight and the low elongation make Dyneema® better in any way. The high strength for low weight is used. The low stretch is a secondary property that is used.

Dyneema® anchor cables

Dyneema® anchor cables are a lot lighter than polyester or steel alternatives. Anchor cables can be longer and deployed more quickly. The ropes have higher durability than ordinary ropes. Chemicals that contaminate the ropes do not influence the rope strength. The strength for low weight is the primary property used here. The abrasion & cutting resistance and chemical resistance are the secondary properties.

Sailing lines

Sailing lines from Dyneema® are lighter and more durable. A lighter boat means more speed, so every kilogram does count. The high strength for low weight, the abrasion & cutting resistance and high bending fatigue are used as the valuable properties.

Paragliding lines

Are lighter than alternatives of the same strength and are more reliable then alternatives. The high strength for its weight and cutting and abrasion resistance are used here.

Fishing nets

Dyneema® fishing nets are a lot lighter than conventional nets. To about 40 % of fuel can be saved by lighter fishing nets. The strength for low weight is used here as the valuable property.

Fish farms

Cage fishing nets made from Dyneema® can be larger without higher risk of damage to the nets. Polyester nets cannot be as large as Dyneema® nets, this is because of the higher strength and lower weight. Lighter weight for its strength and cutting resistance are the valuable property here.

Dyneema® armor

Dyneema® armor for bulletproof vest and vehicles protect personnel from bullets and shrapnel. The tensile strength of the material prevents the bullet from penetrating the Dyneema®. The lightweight for the strength makes gives the same protection for a lower armor weight. The tensile strength is the main property and the lightweight the secondary property.

Dyneema® chains

Dyneema® chains are 8 times lighter then steel chains for the same strength. Making then easier and safer to handle. The high strength for low weight is used as the valuable property.

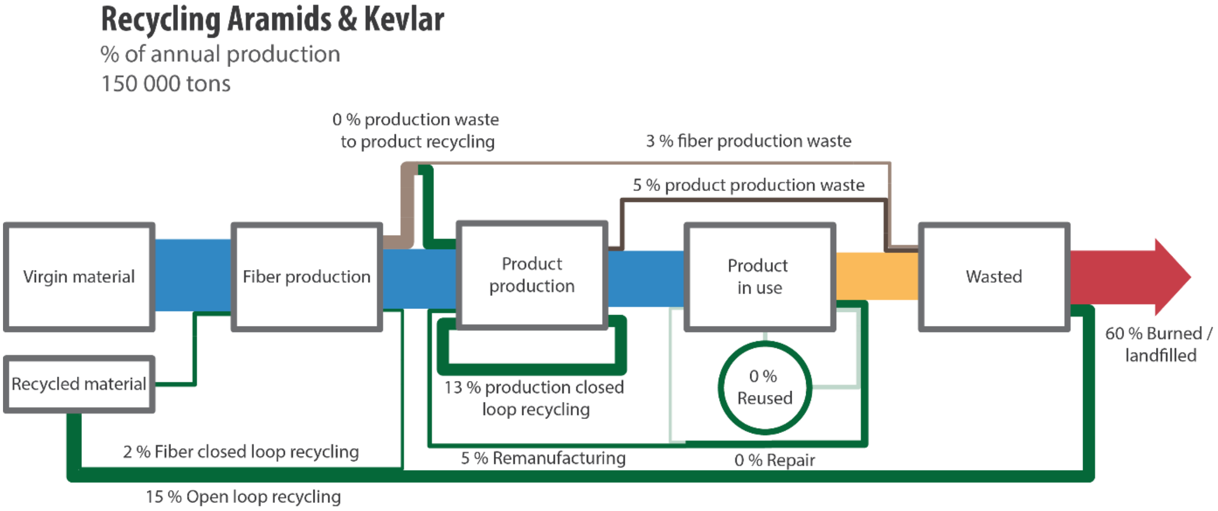
From the above application the following is concluded for the valuable properties of Dyneema® fiber, **table A1**.

Table A1	
Dyneema® strength	**Dyneema® weakness**
Tensile strength per weight unit	No compression strength
Abrasion resistance	Low melting point
Cutting resistance	Suffers from creep
Bending fatigue	
Chemical resistance	

Appendix B

An analysis on how the competing fibers are recycling will provide insights on how *DSM Dyneema® BV* could close their material loops. It was chosen to compare to Aramids, Carbon fiber, Glass fiber and commodity plastics.

Aramid & Kevlar fiber



Graphic 2.32: An overview on the material flow of Aramids & Kevlar fiber. Source: self-made graphic.

150 000 tons annual production **(Prnewswire.com, 2018)** estimation that the annual production has grown from 130 000 tons to 150 000 tons since 2015.

% of the waste streams

Reuse 0 %

No information could be found on the reuse of Aramid & Kevlar products

Repair/Remanufacture ~ 5 %

Assumption based on reuse of shipping ropes into bumpers that is also being done with Dyneema®.

Closed loop recycling ~ = 10 %

Assumption based on the largest aramid manufacturing recycling part of their production waste. Some small other companies recycle production waste or pure aramid products as well **(TEIJIN, 2018)**.

Open loop recycling ~ = 15 %

Assumption based on multiple smaller and larger companies that sell open loop recycled Aramid & Kevlar fibers. The largest Aramid fiber producer has been developing a reverse logistics system for aramid fiber products **(PEACOCK FIBERS, 2018) (Polyvel.nl, 2018)(Altex.de, 2018)** ***(Chmcomposites.com, 2018) (Thomasnet.com, 2018) (chembid.com, 2018).***

Burn/landfilled > 60 %

Technology

The aramid fibers production waste is directly recycled in new products when possible. All other fibers are chopped to small fibers that are either used to make coarse yarn or pulp **(Teijin, 2018)** The products from the current recycling method uses the heat resistance property to provide value. Spun yarn used for packaging and heat protection

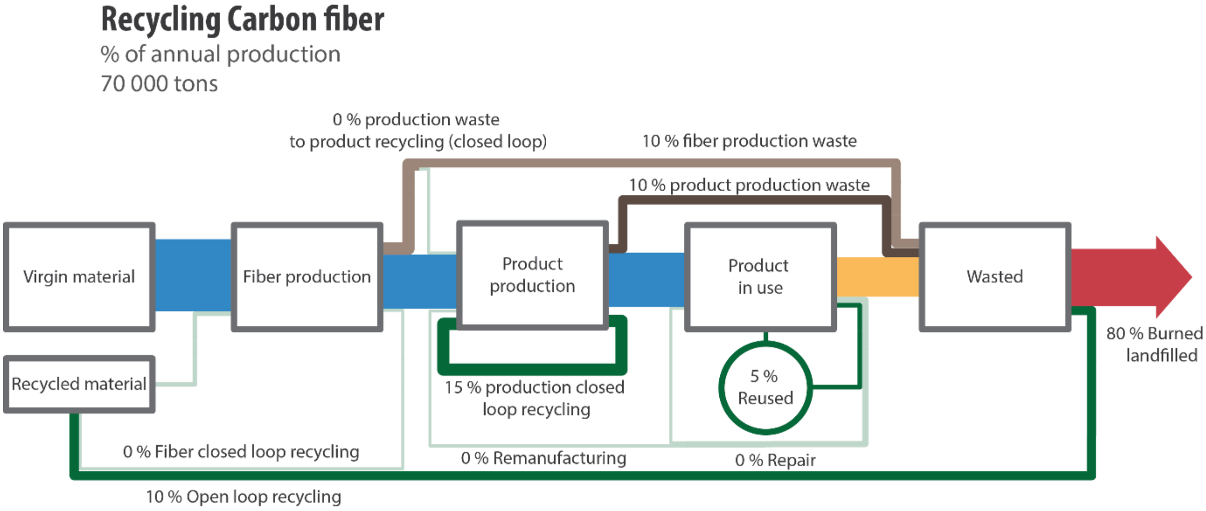
Who

- TEIJN (TEIJIN, 2018)

Good example and largest recycler. Own reverse value chain and quality control for recycled materials. The aramids and Kevlar products are comparable to Dyneema® products, but the recycled products are completely different, possible collaboration could be possible for collecting Dyneema® and Aramid fibers.

- PEACOCK FIBERS, (PEACOCK FIBERS, 2018)
- HARMONY INDUSTRIES, (Harmonyrecycling.com, 2018)
- SECURITY FIBER RECYCLING LLC, (Fiberbrokers.com, 2018)
- R&M INTERNATIONAL SALES CORP, (Rmintl.com, 2018)
- BRENT INDUSTRIES, (Brentindustries.com, 2018)
- CHEMBID *(chembid.com, 2018)*
- Thomasnet *(Thomasnet.com, 2018)*
- Polyvel BV, *(Polyvel.nl, 2018)*
- Altex, CHM composites *(Altex.de, 2018)*

Carbon fiber



Graphic 2.35: An overview on the material flow of Carbon fiber. Source: self-made graphic.

The annual production of carbon fiber was 60,000 tons in 2016. demand is growing a lot which has created the opportunity for recycled carbon fiber **(Barnes, 2018)**

% van de verschillende stromen

Reuse ~5 %

Estimation is that some carbon fiber products are reused e.g. sport equipment

Repair/Remanufacture ~ 0 %

No information found

Closed loop recycling ~ 15 %

Assumption based on that almost all the production waste is **(Barnes, 2018) (CompositesUK, 2018).**

Open loop recycling ~ 10 %

Assumption based on numerous companies that recycle old carbon fiber products or mixed production waste **(ELGCF.com, 2018).**

Burn/landfilled ~ 80 %

Note there that most waste is still in use and will be for some time, most carbon fiber products are still in its first lifecycle, airplanes and wind turbines for example **(Naqvi, 2018).**

Technology

The most used technology to recycled carbon fibers is pyrolysis or mechanical recycling. The fibers are extracted from carbon fiber products by melting the matrix or by chopping carbon fiber products. The fibers from the pyrolysis are chopped to smaller size and used to make non-woven mats or pellets for reinforcement **(Materialsforengineering, 2018) (ELGCF.com, 2018).**

Applications

Low cost and light weight are used as the unique property for selling the material in a non-woven format. The milled fibers provide strength in plastics. The biggest challenge was to find a market for recycled fibers, other than a market for new carbon fiber. The solution was to investigate new application for carbon fiber, like the automotive industry where virgin carbon fiber is currently not used for cost reasons **(Materialsforengineering, 2018).**

Who

- ELG Carbon fiber Ltd. **(ELGCF.com, 2018)**
- ROTH international **(ROTH, 2018)**
- Most large Carbon fiber product manufacturers

Appendix C

1= +/- 250 billion is ¼ of the global agriculture market value in 2015

2= +/- 25 billion 10 % of global supplements market estimated for 2024

3= +/- 2 trillion is about half of the value all the fossil fuel burned in power plants across the world in 2015

4 = +/- 130 billion is 20 % of the total market value of plastics estimated in 2020

Appendix D

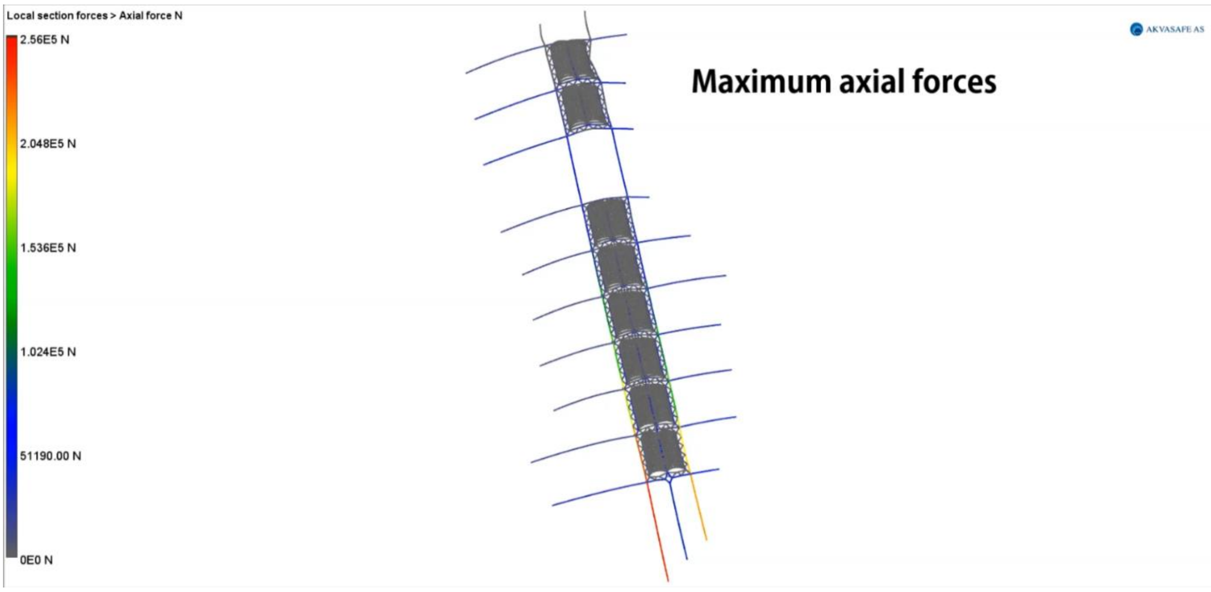


Figure 1: A simulation from Hortimare to analyze the effect of the forces from the current. Source: Schippers, 2019.

Appendix F

The Dyneema® rope structure

The thickness of the fiber and the way the ropes are braided determine if the seaweed can grow on the structure. The thinner the fiber are the better, Dyneema® fibers have a thickness between 0,007 to 0,05 mm, chapter 2.1. This thickness will provide good attachment for the seaweed (Schippers, J. 2019) The EoU mooring ropes are 12 strand braided ropes. These types of ropes provide an excellent surface attachment for seaweed. Ropes with a shield are not suited (Schippers, J. 2019)

Figure 14: A suitable rope for growing seaweed on. Source: self-made image.

Molecular bonding

The molecular bonding of the seaweed depends on if the material is polar or a-polar. Dyneema® is an a-polar material (Vlasblom, 2018). Seaweed cannot attach itself onto non-polar materials (Schippers, J. 2019). Coating on ropes can make the ropes polar (Schippers, J. 2019) The conventional coating is polar and does provide good attachment.

Concluding from the two above points the rope in figure 14 will be suitable for growing seaweed and the rope from figure 15 is not suited for growing seaweed.

Figure 15: A unsuitable rope for growing seaweed on due to the rope shield. Source: self-made image.