ALTERNATIVE ROPE MATERIALS IN TOWED FISHING GEAR TO REDUCE PLASTIC WASTE, A COMPARATIVE STUDY OF MECHANICAL PROPERTIES AND TOLERANCE AGAINST WEAR AND TEAR

Heidi Moe Føre, Hanne Hjelle Hatlebrekke, Eduardo Grimaldo
SINTEF Ocean
Trondheim, Norway

ABSTRACT

This paper presents a comparative study assessing the wear tolerance of rope materials in demersal fisheries, specifically seine ropes and dolly ropes. Fourteen different rope materials were assessed in this study, including conventional and alternative commercially available synthetic polymers, and biodegradable materials including natural fibre ropes and custom-made polyester monofilaments. The sample materials were subjected to controlled wear from a rotating abrasive drum. Tensile testing was performed to determine and compare mechanical properties of the samples before and after exposure to wear. A wear tolerance coefficient has been suggested, i.e. a comparative unit between the different rope material samples and a standard blended polyester/polyethylene rope material as reference.

The tested nylon ropes showed the lowest reduction in breaking strength post wear and thus the highest wear tolerance of all tested materials. Conventional and bio-degradable polyester ropes and monofilaments also performed well compared to the standard reference rope.

The performed tests did not only consider the effect of different raw materials, but the combined effect of material and structural properties. A rope's tolerance to wear may be affected not only by the mechanical properties of the raw material, but also fibre thickness and cross section, and rope thickness, structure and lay of rope.

This study demonstrated the potential of using biodegradable polymers with higher tolerance to wear than conventional non-degradable plastic materials as a circular solution to reduce microplastic pollution caused by demersal fisheries worldwide. Application of alternative commercially available ropes and hard-lay rope structures may increase the tolerance to wear and by that reduce plastic waste.

Keywords: Wear, abrasion, polymers, fishing gear, plastic waste, micro plastics

NOMENCLATURE

Dan	Danline rope (PE/PP blend)
n_o	number of rotations with abrasive drum
PA	Polyamide
PE	Polyethylene
PP	Polypropylene
PET	Polyester, polyethylene terephthalate
PBSA	Polyester, Poly(butylene succinate-co-butylene adipate)
r	strength reduction coefficient
S_n	tensile strength for new, unused samples
S_w	tensile strength post wear
T_w	tolerance to wear/wear tolerance factor
T_{w_ref}	tolerance to wear for reference material

1. INTRODUCTION

1.1 Towed fishing gear and plastic waste

Ecosystem-based fisheries management is fundamental to guarantee a sustainable exploitation of fish stocks. However, sustainable fisheries are not only affected by stock availability and their distribution, but they also suffer from and contribute to different pollutions such as plastic waste [1][2].

Decades ago, synthetic materials revolutionized the fishing industry worldwide by making gear last longer and resist damage [2]. Materials such as nylon and polyethylene used in nets and ropes provide flexible fishing gear at low costs, contributing to the large increase in catches in the past 70 years. However, large-scale use of non-degradable materials in the ocean has provided challenges such as ghost fishing by lost or discarded fishing gear, and the release of macro-, meso-, and microplastics into the environment. It is estimated that 640,000 tonnes of plastics from fishing gear enter the ocean each year, representing about 10% of all marine debris [3]. The plastic pollution is a result of wear and degradation of ropes and nets when gear is deployed, in use, and after they have been lost at sea.

Marine litter and microplastics have already been identified as one of the anthropogenic (man-made) pressures that can affect ecosystems and ecosystem services, and should be addressed in fisheries management worldwide [3][4]. Demersal trawling and seining are known contributors to marine litter and microplastics, representing high gear-specific relative risk of plastic waste [3]. Dolly ropes used by demersal trawlers have been a source for debate and research for many years. Dolly ropes are extensively used to protect the trawl netting from wear and tear caused by contact with the seabed (FIGURE 1).

FIGURE 1: USED DOLLY ROPES ON DEMERSAL TRAWL.

The use of dolly ropes is common among several types of demersal fisheries around the world, but mainly found in Europe around the North Sea, English Channel, Irish Sea, and Bay of Biscay [5]. Dolly ropes are also used by pelagic and demersal trawlers in the Barents Sea and around Svalbard. According to the Dutch DollyRopeFree-project [5], a trawl vessel owner purchases between 325 and 3500 kg of polyethylene (PE) dolly ropes yearly, a figure which depends on the type of fishery, the type of seabed (sand/clay/stones/rock), and the size of the net. The life span of a dolly rope ranges from three weeks to up to six months. Fishers replace some or all sets of dolly ropes quite frequently, and old dolly ropes are brought to port as end-of-life gear. However, dolly rope frays easily and 10–25% ends up tearing off at sea [5], mainly due to the wear the net suffers against the seabed during trawling. It has been estimated that in the North Sea, at least 25 tons of dolly rope yarn end up in the ocean each year, and historically, similar amounts are believed to have been thrown overboard during maintenance work. Worldwide, fisheries probably generate multiple times this amount of plastic waste. It is for example estimated that Norwegian demersal trawlers generate about 60 tons of plastic waste from dolly ropes [3].

Other fisheries also suffer from wear and tear of fishing gear and end up becoming a source of plastic pollution. In Norway, demersal seine ropes and trawls are the highest contributors to plastic pollution from fisheries [3]. Here, demersal seines is the second most used fishing gear to harvest demersal fish species. They are also commonly used in Europe, especially in Denmark (anchor seining) and Scotland (fly dragging). During demersal seining, the net is towed by an up to 4000 m long leaded polyethylene/polypropylene (PE/PP) rope with a diameter of 36-60 mm (FIGURE 2). The ropes are laid on the seabed and then towed to create visual effects, sand clouds, and noise, herding the fish into the net. Seine ropes are dragged along the seabed over a considerable distance, resulting in high frictional damage in the form of wear and tear of rope strands and abrasion damage (FIGURE 3). Seine ropes have been estimated to lose 20-30% of their plastic mass every season (lasting for approximately six months) due to wear and tear [3]. In Norway, this results in 80-100 t of plastic waste annually by demersal seine fisheries, while globally, more than 300 t of microplastics are produced each year [3].

1.2 Wear, tear and abrasion of demersal seine ropes and dolly ropes

Seine ropes are normally made of bundles of polymer fibres (split fibres, multifilaments or monofilaments) called yarns, which are twisted and/or braided to form a compact rope (FIGURE 2). Dolly ropes are typically made of split fibre yarn, sometimes also containing monofilaments (FIGURE 2). It is common to observe frayed ropes and dolly ropes on the underside of used demersal fishing gear, due to contact with the seabed during towing. Such damage is normally a combination of broken individual fibres and abrasion (material loss) of fibres [6]. Broken fibres are a consequence of tensile or shear overloads, or a combination of these [7]. In practice this is a result of fibres being caught by the rough sea bottom and pulled (by the towing vessel) until they are torn or cut off by a sharp edge. Such damage may tear off pieces of fibres and yarn, which are released into the surrounding water. Abrasion damage happens when the sea bottom has a grinding effect on the material, which most likely will produce and release small particles (e.g., microplastics).

Seine ropes that are dragged along the seafloor will be subjected to wear and probably a gradual degradation until they ultimately may break. When ropes, yarn and fibre break off, larger pieces of yarn and fibres may be released. It is probable that this will contribute to a larger volume of plastic pollution that released microplastics from abrasion. However, in time these larger pieces of plastic will disintegrate into microplastics.

Wear (including abrasion) and tear of ropes may lead to fraying, loss of mass, and reduced strength. Assessment and quantification of abrasion damage cannot be based on visual inspections alone; it is not always the most frayed ropes that have the highest strength reduction or material loss. Common ways to measure the effect of wear and tear are either weighing to establish reduced mass or tensile testing to establish reduced tensile strength. It is often difficult to measure weight loss of fibre ropes and nets, as the observed wear and tear may not necessarily lead to a measurable weight loss but may be caused by local fractures in fibres [6][7]. Thus, it is common to quantify this kind of damage through tensile testing, i.e., comparing the tensile strength of unused and used ropes [8].

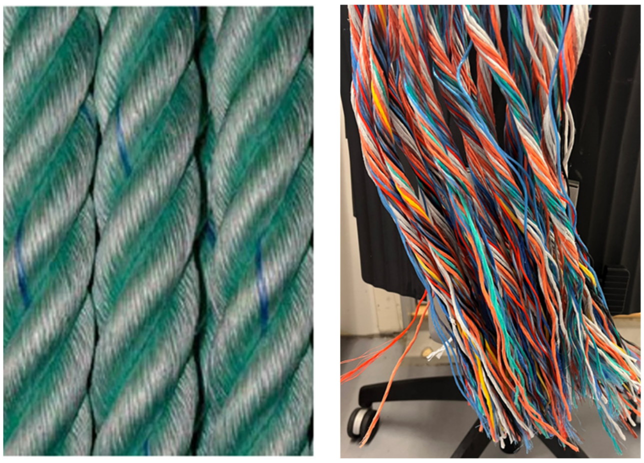

FIGURE 2: NEW 50 mm SEINE ROPE (LEFT), AND UNUSED DOLLY ROPE (RIGHT).

FIGURE 3: USED SEINE ROPES WITH VISIBLE WEAR.

1.3 Measures to prevent plastic waste in fisheries

A major source of plastic waste from fisheries are seine ropes and dolly ropes that are in contact with the sea floor and thus subjected to wear and tear and release plastic particles to the surroundings. Replacing such ropes with alternative ropes may act as mitigation measures. Different strategies can include applying ropes with higher tolerance to wear and abrasion, and/or ropes made of natural fibres or bio-degradable polymers [9] [10] [11].

This study was aimed at assessing the abrasion resistance of alternative synthetic, natural and bio-degradable materials that may be relevant for use in demersal seine ropes and dolly ropes. Specifically, this study was seeking to answer the following research questions:

1. May the use of alternative materials reduce microplastic waste and thus the negative effects of plastics in the marine environment?
2. Which material is best suited for demersal seine ropes and dolly ropes in bottom trawling?

This paper presents a study on wear tolerance of different rope materials subjected to controlled application of wear under same conditions in a laboratory. The ropes have been ranked based on their quantified resistance to wear, providing general recommendations on how to potentially increase tolerance to wear. Finally, particles released during abrasion and wear have been studied.

2. MATERIALS AND METHODS

2.1 Rope samples

Fourteen different rope materials were assessed and compared in this study, including conventional synthetic polymer fibres, natural fibres, and bio-degradable polymers, all described in TABLE 1. This included six different Danline ropes and yarns. Danline is a commercial trade name for ropes made of yarns containing split fibres of blended polyethylene (PE) and polypropylene (PP). These ropes are widely used in gear for demersal seining and trawling worldwide, and Danline fibres are also used in Dolly Ropes. The so-called hard and soft yarns in samples Dan-1 to Dan-4 (TABLE 1) are special blends of PE and PP produced by Selstad AS (Måløy, Norway), while Dan-5 and Dan-6 are samples of commercial off-the-shelf Danline ropes. All Danline samples, except Dan-5, consisted of single yarns obtained from either spools of yarn or produced ropes. The majority of the tested Danline yarns, except for Dan-5, had a diameter of approximately 3.5 mm (FIGURE 4, TABLE 2). The imported Dan-5 had much thinner yarn. This was a three-strand rope, and each strand consisted of eight yarns as opposed to 3-4 yarns for the other Danline ropes. For testing, the strands of Dan-5 were split in two, so that each sample consisted of four yarns and measured approximately 5 mm in diameter.

An additional four commercially available synthetic polymer ropes were included in this study: a typical

Norwegian dolly rope (FIGURE 2) and three off-the-shelf ropes of different raw materials (FIGURE 5). The dolly rope consisted of different fibres of unknown origin and varying thickness, but they resembled twisted Danline and PE split fibres typically used in ropes, and nylon monofilaments. Nylon was a common braided eight strand nylon rope that measured 5 mm in wet condition, while the PET samples were one strand of a three-lay 6 mm polyester rope. The PE-rope had thicker fibres than Nylon and PET, a braided structure, and an oval cross section.

Two different ropes containing natural fibres were also included (FIGURE 4), i.e., sisal fibres (*Agave sisalana*) and viscose fibres made from wood [12]. Finally, two different biodegradable polyester monofilament products were tested, including a twisted rope (Bio-R, TABLE 1, FIGURE 4) and a dolly rope (Bio-D). Bio-R was a custom-made rope by LG Chemicals made of monofilaments of biodegradable, semi-crystalline polyester Poly(butylene succinate-co-butylene adipate) (PBSA) [13]. The biodegradable dolly rope also consisted of a biodegradable polyester monofilament, commercially known as GreenRope which has been specially developed for dolly rope applications [14].

To promote comparability between different rope samples, we selected samples as close to 4 mm in diameter as practically possible (TABLE 2), and both yarns, braided or twisted ropes, and individual strands of rope were tested (TABLE 1). The yarns and fibres in the dolly rope (Dolly) had varying thicknesses, with an average of 2.4 mm for the tested samples. The rope thickness in TABLE 2 is given for wet samples. Nylon, Sisal and Viscose swelled during soaking, resulting in an up to 1 mm increase in thickness.

TABLE 1: SHORT NAME AND DESCRIPTION OF TESTED ROPE SAMPLES

Rope samples	
Dan-1	Danline (PE/PP) -single hard yarn from spool
Dan-2	Danline -single soft yarn from spool
Dan-3	Danline -single hard yarn from twisted rope
Dan-4	Danline -single soft yarn from twisted rope
Dan-5	Danline -four yarns from imported twisted rope
Dan-6	Danline -single yarn from common twisted rope
Dolly	Dolly rope - split fibre and monofilaments
Nylon	Braided nylon multifilament rope
PET	Strand from twisted multifilament polyester rope
PET	Braided polyester monofilament rope
Sisal	Strand from twisted sisal rope
Viscose	Strand from twisted wood fibre rope
Bio-R	Strand from twisted PBSA monofilament rope [9]
Bio-D	Monofilament from biodegradable polyester dolly rope

FIGURE 4: Dan-3 ROPE AND TEST SPECIMENS (YARN) FROM Dan-5, Dan-2 AND Dan-1 (RIGHT TOP TO BOTTOM).

FIGURE 5: Nylon ROPE, PET STRAND AND PE ROPE, ALL AFTER WEAR.

FIGURE 6: FROM UPPER LEFT: Sisal STRAND (WITH WEAR), Viscose ROPE, Bio-R ROPE AND Bio-D MONOFILAMENTS.

TABLE 2: SAMPLE THICKNESS, NUMBER OF REPLICATES OF NEW AND WORN ROPE MATERIAL, AND NUMBER OF ROTATIONS OF THE ABRASIVE DRUM.

	Wet sample thickness [mm]	Replicates (new/worn)	Rotations
Dan-1	3.5	10 /10	80
Dan-2	3.5	10/10	21
Dan-3	3.5	10/14	20
Dan-4	3.5	10/10	60
Dan-5	5	10/8	60
Dan-6	3.5	6/11	20
Dolly	1.5-3.5	30/30	30
Nylon	5	5/10	80
PET	3.5	5/10	80
PE	2 x 5	3/5	80
Sisal	5.5	5/5	80
Viscose	4	5/5	5
Bio-R	4	10/10	80
Bio-D	1.5	15/14	80

2.2 Method for testing of abrasion tolerance

The 14 different rope samples were subjected to abrasion, wear, and tear through a test machine named MILA 200 WET (Buraschi Italia, FIGURE 7). This machine has a rotating drum which was covered in 220 grit grinding paper for these tests. A water tank ensured that the materials were wet during testing. After this controlled application wear, the strength of each sample was found and compared to the strength of new samples.

Tensile testing was performed to determine and compare the mechanical properties of the samples before and after controlled exposure to wear. Both tensile strength (breaking force), elongation at break, and stiffness found from a strain-stress curve can be applied to assess the effect of wear and tear on rope samples. In this work, abrasion tolerance has been quantified based on ultimate tensile strength.

Procedure for application of wear

Samples measuring 1.2 m were soaked overnight in tempered fresh water prior to testing of tolerance to wear. The rotating drum was covered with new unused grinding paper before each test, and rope samples were placed along the lower part of the drum in the water tank. At one side of the drum, the ropes were fixed to a bar above the drum (FIGURE 7), while the other end of each rope was placed over another fixed bar (FIGURE 8). Weights of 100 g were attached to the loose rope ends to provide suitable pretension during testing [6]. For the small diameter samples of the dolly ropes (Dolly and Bio-D, TABLE 1), 60 g was applied due to the reduced cross section area and strength compared to the thicker ropes. The Viscose ropes were also pretensioned by 60 g due to their low mass and strength ([15], ISO 3790). The drum was rotated counterclockwise, with relative movement from the fixed end towards the end with the weights.

The rope samples were in general exposed to sets of 20 rotations until wear was visible to the eye. The maximum number of rotations was 80. There were two exceptions from this step in the procedure: PET started fraying after few rotations but did not show any reduction in strength after 20 rotations. Thus, it was decided to increase the number of rotations to the maximum of 80. The other exception was the wood fibre yarn that did not endure 20 rotations but showed major wear after only five rotations, at which point breaking strength was assessed for this material. At least five samples of each rope material were exposed to wear from the abrasive drum (TABLE 2). Additional replicates were included for materials that showed large variations in strength post wear. A total of 30 replicate Dolly rope samples were tested in both new and worn condition due to large variations in mechanical properties.

Procedure for tensile testing

After the controlled application of wear, the tensile strength of each sample was found using a benchtop testing machine from Tinius Olsen (H10KT, Tinius Olsen TMC, PA, USA) with a load cell of 5 kN. All the measurements were performed in compliance with ISO 1806:2005 and ISO 2307:19.

For comparison, tensile strength was determined for three or more samples of new material (TABLE 2). Additional replicates were included for materials that showed large variations in strength.

The procedure for the tensile testing was as follows: A wet sample was mounted onto the tensile testing machine with bollard grips to prevent premature failure at the grips (FIGURE 8). The specimen was stretched at a constant velocity of 200 mm per minute.

The ultimate tensile strength is given both as ultimate stress, i.e., ultimate load divided by cross-section area [N/mm]/[MPa], and in kilograms [kg] which is the common trade standard.

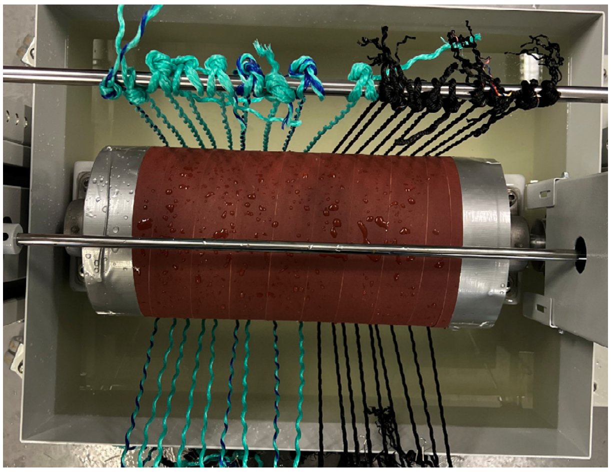

FIGURE 7: TOP VIEW OF THE ABRASION MACHINE SHOWING Dan-5 (GREEN) AND PET (BLACK) SAMPLES SUBJECTED TO WEAR FROM THE ABRASIVE DRUM.

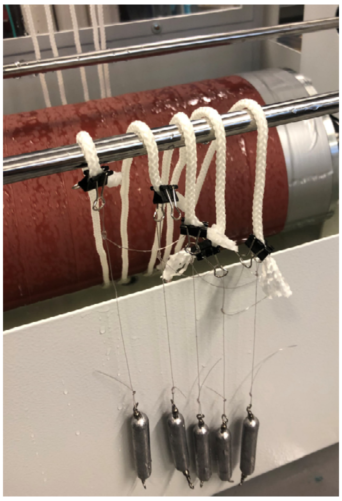
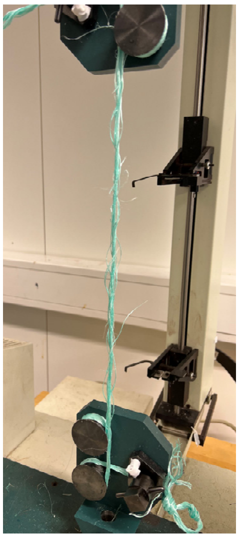

FIGURE 8: NYLON SPECIMENS WITH 100 G WEIGHTS ATTACHED (LEFT). TENSILE TESTING OF WORN DANLINE YARN (RIGHT).

2.3 Quantification of tolerance to wear

Wear has been quantified as the difference in tensile strength before and after applied wear. Assuming that each rotation of the abrasive drum results in the same amount of wear, wear has been given per number of rotations. Finally, the wear tolerance of the different materials is normalised by the wear tolerance of Dan-6 (common off-the-shelf Danline). The mathematical expression for the tolerance to wear of a given rope (tolerance coefficient) is then as follows:

$$T_w = \frac{n_o}{r \cdot T_{w\_ref}} \qquad (1)$$

where n_o is the number of rotations with the grinding paper drum (TABLE 2), and T_{w_ref} is the wear tolerance of a selected reference rope (Dan-6 in this study). The strength reduction coefficient post wear is given by:

$$r = \left(1 - \frac{S_w}{S_n}\right) \qquad (2)$$

where S_w is the average tensile strength measured for test samples with applied wear, and S_n is the average tensile strength measured for test samples of new rope material (unused condition, without wear).

The diameter of the test piece may also affect wear tolerance, however this has not been included in eq. 1 since this effect is not known and it was sought to have similar thickness for the different material samples (see discussion).

2.4 Collection and studies of microplastics

The water tank of the MILA 200 WET was emptied after one to three days of use. The water was filtered through a 64 μm mesh, and the collected particles were dried and studied through a lens.

3. RESULTS AND DISCUSSION

3.1 Tensile strength

The tensile strength pre wear (new samples) varied between the different rope samples, ranging from 13 kg for Bio-D to 380 kg for Dan-5 (FIGURE 9 and FIGURE 10). Tensile strength is highly dependent on the thickness of the samples, which varied between 1.5 mm and 5 mm. Thus, to discuss the differences in strength between the types of rope samples, strength was divided by the cross-section area to establish the ultimate tensile stress. Disregarding the effect of sample thickness, PET was the strongest rope sample in new condition (FIGURE 11), followed by multiple synthetic ropes including Bio-R. The natural fibre ropes and Bio-D were in the order of three to six times weaker than the other ropes.

Comparing the tensile strength pre and post applied wear (FIGURE 9 and FIGURE 10), it was found that all samples showed signs of degradation through reduced tensile strength post wear. However, particularly Nylon showed very little loss in strength even though it was subjected to the maximum amount of applied wear (80 rotations, FIGURE 8), while Viscose had close to no strength left after only 5 rotations.

The strength reduction was not always in accordance with wear visible to the eye, i.e., the perceived severeness of observed fraying was not necessarily in proportion to reduced strength. Examples of this was PET that developed extensive fraying during wear but showed a moderate reduction in tensile strength. While PE only showed small signs of wear, the tensile strength was reduced by 50 % (FIGURE 10).

3.2 Tolerance to wear

Considering the strength loss per rotation, the tolerance to wear normalized by the tolerance of the conventional rope yarn Dan-6 is given in FIGURE 12. Ropes samples with a wear tolerance coefficient (eq. 1) greater than 1 showed improved wear tolerance compared to a standard Danline rope yarn (Dan-6), whereas a factor of less than 1 showed a lower wear tolerance.

The most wear-tolerant rope sample tested was the braided nylon rope which showed 12 times higher wear resistance than the standard Danline yarn. Additionally, the bio-degradable dolly rope (Bio-D) showed high wear resistance with a tolerance six times higher than Dan-6. Dan-5, PET, and Bio-R also performed well with a wear tolerance factor of 3. Dan-5 performed significantly better than the other Danline qualities tested.

Dan-2, Dan-3, Dolly and Viscose were more susceptible to wear during these tests than the reference Dan-6. Especially Viscose experienced severe fraying after only a few rotations of the abrasive drum and showed a particularly low tolerance to wear.

The performed tests do not only consider the effect of different raw materials, but the combined effect of material and structural properties. A rope's tolerance to wear may be affected not only by the mechanical properties of the raw material, but also fibre thickness and cross section, and rope thickness, structure and lay of rope. Thus, the results for Danline yarn are not directly comparable to results for hard laid rope samples Nylon and PET, as the effect of the twisted rope lay is not included in these tests on single yarn, and only partly included for Dan-5. In general, thicker fibres may increase wear resistance of ropes, as fibres may be less likely to break. Thus, multifilaments (bundles of very thin fibres) and split fibres (cut from thin films) may be susceptible to wear. Regardless of this fact, the multifilament Nylon rope performed very well in these tests, yielding the highest wear tolerance coefficient. This rope had a hard-lay braided structure, which may make the individual fibres less accessible to the grits of the abrasive drum, and also limits the number of strands and fibres that are subjected to wear (as opposed to a twisted rope where all strands are in contact with the rotating drum or the seafloor). The Nylon rope samples were in addition relatively thick. A thicker rope may experience an increased wear tolerance, as they will have a smaller surface to volume ratio, and the increased wear due to a larger contact area may be less than the increased inherent tensile strength. This effect is difficult to quantify without further investigations.

Another surface to volume ratio effect may be present for the PE rope: The rope had a rectangular shape with a breadth and thickness of 5 and 2 mm respectively. The full breadth of the rope was in contact with the abrasive drum, and it can thus be assumed that this rope had a relatively large surface abrasion area with regards to its volume. This may thus affect the PE rope's wear tolerance coefficient negatively.

Comparing the different Danline qualities, Dan-5 yielded a relatively high wear tolerance coefficient. This may be due to the fact that these samples consisted of thinner yarns with a perceived harder twist, and a relatively large sample thickness. The detailed polymer composition is unknow for all Danline qualities (trade secrets), and differences between rope samples could obviously also affect the relative wear tolerance. Dan-2 and Dan-3 produced a somewhat low wear tolerance coefficient. This may be affected by the fact that these were subjected to less rotations than the comparable Dan-1 and Dan-4. The grinding paper may be worn during testing, producing less and less damage per rotation. In conclusion, disregarding Dan-5, no differences in wear tolerance have been shown between the Danline qualities.

The tolerance to wear may also be affected by the grit size of the abrasive drum. In this study the grit size was chosen based on the following criteria: it should provide a significant reduction in strength and relatively low variations in results ensuring adequate reproducibility. In practise, the seafloor may be rougher than the selected grinding paper. Choosing a rougher grinding paper may reduce reproducibility.

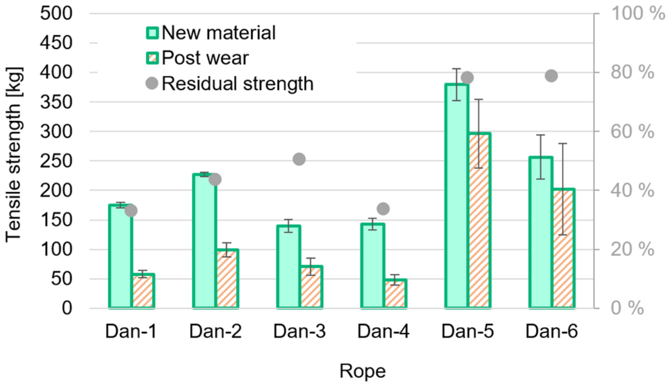

FIGURE 9: AVERAGE TENSILE STRENGTH AND STANDARD DEVIATION FOR VARIOUS DANLINE YARNS PRE AND POST APPLIED WEAR [KG], AND RESIDUAL STRENGTH AS PERCENTAGE OF NEW MATERIAL.

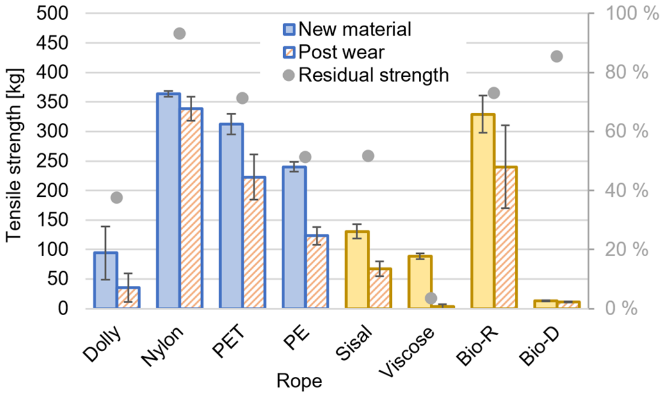

FIGURE 10: AVERAGE TENSILE STRENGTH AND STANDARD DEVIATION FOR SAMPLES OF VARIOUS SYNTHETIC POLYMER FIBRES, NATURAL FIBRES AND BIO- DEGRADABLE FIBRES PRE AND POST APPLIED WEAR KG], AND RESIDUAL STRENGTH AS PERCENTAGE OF NEW MATERIAL.

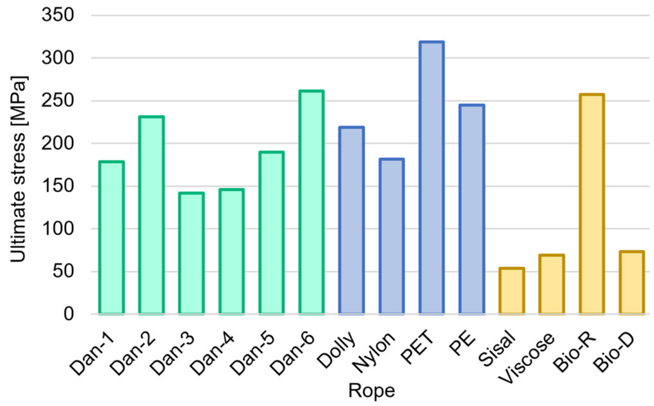

FIGURE 11: AVERAGE ULTIMATE TENSILE STRESS FOR THE VARIOUS NEW ROPE SAMPLES.

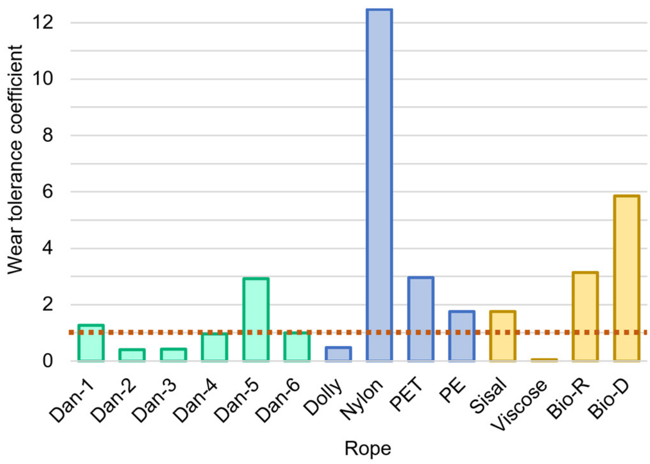

FIGURE 12: WEAR TOLERANCE (eq. 1) FOR THE VARIOUS ROPES. THE RED DOTTED LINE INDICATES THE REFERENCE VALUE OF 1 (BASED ON Dan-6).

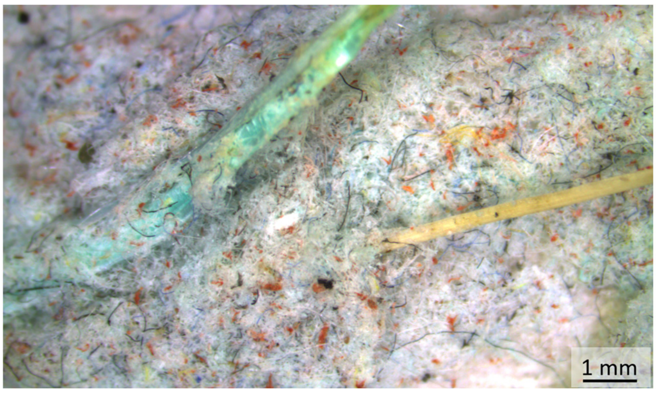

FIGURE 13: MICROPLASTICS AND OTHER PARTICLES PRODUCED DURING APPLICATION OF WEAR.

3.3 Release of microplastics

Particles were produced during application of wear and were visible both in the water tank and on the grinding paper. The particles in the water were collected, and in total they filled a small volume of approximately 1 cm^3 (FIGURE 13). A large fraction of these particles were microplastics (i.e., plastic particles of 0.001-5 mm in size), but there were also a great deal of longer fibres in the collection. The particles could to a large degree be identified by colour and shape, and from the ropes that had been tested in the different batches of water.

The ropes that seemed to produce the most particles were viscose and polyester. Viscose is a natural fibre that will not pollute the environment in the same manner as microplastics. The released polyester fibres were very thin (µm) but often more than 5 mm long. So, although this rope showed improved wear tolerance compared to conventional ropes, it has the potential to release large quantities of plastic particles.

A large number of colourful pieces of film was observed, which must originate from the conventional dolly rope. A few fibres from sisal (FIGURE 13) and nylon were also identified, in addition to turquoise particles from the Danline and polyethylene ropes.

3.4 Measures to increase wear tolerance of ropes and reduce plastic waste

Based on the experimental work presented, the following measures may increase wear tolerance of ropes in fishing gear:

- Choose materials with increased tolerance to wear, such as nylon, polyester or UHMWPE*
- Produce hard-lay ropes of twisted yarns.
- Avoid twisted multifilament ropes, as they may release pieces of filaments.
- Braided ropes may increase tolerance to wear if only limited parts of the rope circumference, i.e. a limited number of fibres, are subjected to wear.
- Thicker fibres may increase tolerance to wear
- Conventional dolly ropes have a low tolerance to wear. Replacing these with monofilament polyester ropes (Bio-D) may increase the wear tolerance of dolly ropes.

**UHMWPE is short for Ultra-high-molecular-weight polyethylene and includes Dyneema®. These materials are known for their high abrasion resistance. Ropes of this material has not been included in these tests due to the high tensile strength of such materials and the limitations of the applied load cell.*

Plastic waste can also be reduced by replacing plastics with natural fibres or bio-degradable fibres. Both natural sisal fibres and the two bio-degradable monofilaments show improved tolerance to wear compared with conventional Danline material.

4. CONCLUSION

Plastic waste can be reduced by replacing conventional ropes in fishing gear with more durable ropes and bio-degradable ropes made of natural fibres or custom-made bio polyester. Several of the tested rope samples show increased tolerance to wear. Both stronger raw materials, hard laid rope structures and monofilaments appear to have a positive influence on wear tolerance.

ACKNOWLEDGEMENTS

This work was financed by the Norwegian Industrial Seafood Research Fund and the Norwegian Research Council. We would like to thank Mr. Knut Steffen Solvåg from Selstad AS, Mr. Gerard Nijhoving from Senbis Polymer AS, and Mr. Young Kim from LG Chemicals Co. Ltd. for their collaboration in this project and for providing the samples to carry out the laboratory tests.

REFERENCES

[1] Jambeck, J.R., et al., 2015. Plastic waste inputs from land into the ocean. Science. 347(6223): p. 768-771. https://doi.org/10.1126/science.1260352

[2] European Commission, 2018. A European Strategy for Plastics in a Circular Economy. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2018%3A28%3AFIN (accessed on 19 October 2022)

[3] Syversen, T. Lilleng, G. Vollstad, J. Hanssen, B.J. Sønvisen, S.A., 2022. Oceanic plastic pollution caused by Danish seine fishing in Norway, Mar. Pollut. Bull. 179. 113711. https://doi.org/10.1016/j.marpolbul.2022.113711

[4] United Nations Environment Programme, 2021. From Pollution to Solution: A global assessment of marine litter and plastic pollution. Nairobi. ISBN: 978-92-807-3881-0. https://www.unep.org/resources/pollution-solution-global-assessment-marine-litter-and-plastic-pollution (accessed on 19 October 2022).

[5] DollyRopefree, 2018. http://www.dollyropefree.com/ (accessed October 19th 2022).

[6] Moe Føre, H., Gaarder, R.H., 2018. RobustNet - Documentation of mechanical properties and dimensions for netting in aquaculture nets. SINTEF Ocean, report number 2018:00971.

[7] Moe, H., Gaarder, R.H., Olsen, A., Hopperstad, O.S. (2009). *Resistance of aquaculture net cage materials to biting by Atlantic Cod* (Gadus morhua). Aquacultural Engineering **40**, 126–134.

[8] Su, B., Føre H.M. and Grimaldo, E., 2019. A comparative study of mechanical properties of biodegradable PBSAT and PA gillnets in Norwegian coastal waters. Proceedings of the 38th International Conference on Ocean, Offshore and Arctic Engineering (OMAE), Glasgow, Scotland. https://doi.org/10.1115/OMAE2019-95350.

[9] Odd G. Brakstad, Lisbet Sørensen, Sigrid Hakvåg, Heidi M. Føre, Biao Su, Marianne Aas, Deni Ribicic, Eduardo Grimaldo, 2022. The fate of conventional and potentially degradable gillnets in a seawater-sediment system, Marine Pollution Bulletin 180, 113759, https://doi.org/10.1016/j.marpolbul.2022.113759.

[10] European Commission, 2020. Biodegradability of plastics in the open environment. Scientific advice mechanism (SAM). Group of Chief Scientific Advisors. Scientific opinion No. 10, December 2020. ISBN 978-92-76-23785-3 https://data.europa.eu/doi/10.2777/690248

[11] European Commission, 2020. Study on Circular Design of the Fishing Gear for Reduction of Environmental Impacts. EASME/EMFF/2018/011 Specific Contract No.1. Final report. July 2020. ISBN 978-92-9460-199-5. https://op.europa.eu/en/publication-detail/-/publication/c8292148-e357-11ea-ad25-01aa75ed71a1

[12] Fiskeribladet (2021). Bottom trawler has testet a dollyrope made of wood-fibre. Fiskeribladet. January 03, 2021. https://www.fiskeribladet.no/tekfisk/-hermes-har-testet-ut-tralmatter-laget-av-tre/2-1-1135629

[13] Polymer database 2022. Poly(butylene succinate-co-butylene adipate) (PBSA). https://polymerdatabase.com/Polymer%20Brands/PBSA.html

[14] Senbis AS. Marine degradable fishing net protection (dollyrope). https://www.senbis.com/products/marine-degradable-fishing-net-protection-dolly-rope/

[15] Moe, H., Olsen, A., Hopperstad, O. S., Jensen, Ø., Fredheim, A. (2007). Tensile properties for netting materials used in aquaculture net cages. Aquacultural Engineering 37, 252–265.