Materials science

The materials used for fishing nets all made of synthetic fibres. When selecting which material to use to make a net, the fisherman or seine maker bases his choice on his knowledge of the properties and price of the given material. Also in connection with maintenance and repair it is important to know the properties of the materials to avoid making a weak link out of poor materials.

The introduction of synthetic fibres after World War II was somewhat of a revolution, not least within fishing. The reason for this is primarily that synthetic fibres do not rot as did the natural fibres of hemp, cotton, sisal, etc. used until then. Over time, the plastics industry has benefitted the world with a vast number of different plastics materials. They may soon replace any material, as plastics can be designed with almost any kind of properties.

Raw materials

Even though the manufacture of synthetic materials is relatively simple, we will not go into detail here. The raw materials used in the manufacture are various natural products: oil, carbon, lime and various salts. Molecules (monomers) are manufactured from these products, having the ability in further chemical and physical processes to combine to form long chains (i.e. they polymerise). The result is a mass of synthetic materials that contain only very long molecules. The mass is cut into small pieces (pearls), which are then ready for the final manufacture of the fibres. These are formed in a so-called extrusion process. In this process the pearls are melted and pressed out through small pipes. Finally, the extruded fibres are stretched 4-5 times whereby they achieve their final diameter, strength and elasticity.
During the 1980s and 1990s, a limited number of high-strength materials emerged, enabling the manufacture of stronger lines. These materials have made it possible to reduce the diameter of the net used and replace wire and steel wire ropes made of iron. Firstly, the increase in line strength is very significant as the towed tools offer less towing resistance and thus reduced expenses for the fisherman. Secondly, the reduced net diameter and the replacement of iron wires and wire ropes facilitate tool manufacture and handling and reduce the tool weight. The new materials are partly manufactured from new raw materials, partly from materials that have been treated in a new way, and finally from composite products made of two or more known raw materials.

The new materials are sold under names such as Kevlar, which is a new carbon fibre, Danline, which is a composite product, and Karat, which is a polypropylene fibre that is stretched beyond what is normal. The same applies to Dyneema and Spektra, which are manufactured on the basis of polyethylene. The biggest problem with the new materials is the price.

### From synthetic material to lines and ropes

The basic material in any net or rope is the filaments that are joined in large or small numbers and spun into a so-called yarn. These thin yarns are further spun and braided – one or more times – to increasingly thicker lines and ropes.

### Fibre types

There are several different fibre types that have either been produced from the actual extrusion or in the different processing of the extruded fibres.

*Continuous filaments* are very thin threads of virtually infinite lengths. They are similar to silk, and a yarn manufactured from continuous filaments will typically contain filaments that are up to 1 km long. They will have a shiny appearance, at least as long as they are untreated.

### Fact Box

**New fibres save lives**

Fishermen are not the only ones to benefit from the special properties of the new high-strength materials. In extreme situations the materials save lives: They are used in the manufacture of bullet-proof vests and police and military helmets. Cars can also be coated with plates of these fibres (e.g. on the inside of the doors) and thus be protected from gunfire.

The materials are also used in the manufacture of fencing costumes, crash helmets and other special safety equipment, such as in clothing for people working with chainsaws.
Staple fibres are made of continuous filaments that have been cut into 5-10 cm pieces. Lines spun from staple fibres are “hairy”, so called due to the many loose ends sticking out. This makes them easier to hold onto and keeps the knots better in place. These lines thus have a cotton- or wool-like appearance.

Monofilaments is the name used for single filaments that are strong enough to be used alone. They are known from fishing lines, but they are also used in a spun form in the manufacture of other forms of nets and ropes.

Split fibres are manufactured by stretching plastic strips to the extent that they split down the middle. Lines manufactured from split fibres are somewhat similar to bast in that they contain fibres of irregular length and thickness. Split fibre rope can also be manufactured from plastic strips which have been cut mechanically immediately after extrusion.

Twisting and braiding
The fibres of the finished yarn or rope can be joined in many different ways. The method used is based on whether a particular property in the finished product is desired. The lines that form part of the actual net manufacture (called net mending twine by net makers) can either be twisted or braided.

Twisted lines
A finished rope often contains several “levels” of twistings. A normal line for manufacturing trawl nets is thus normally manufactured from a number of single fibres that pre-twisted. Three of these fibre bundles – confusingly called nets – are subsequently joined by post-twisting them into the finished line.

In ropes it is common to have twistings at even more levels. The direction of the twistings is important for the properties of the finished rope. You talk about twistings in the S or Z-direction, or an S or Z-lay. The letters refer to the direction of the yarn in the thread. Normally, the direction will vary from spinning to spinning, so that the pre-twisting is S-laid, and the post-twisting is Z-laid. A subsequent lay will then again be S-laid. This change is designed to make the rope “neutral”, i.e. to prevent it from untwisting when subjected to load. It is difficult to make a twisted line neutral, which can be seen if you hang a weight at the end of a line. Normally, it will start to rotate and untwist the line.

Braided lines
In the braiding of a line the yarns are placed in such a way that they cross each other in the diagonal direction of the net. Braided lines are actually tube-shaped with the size of the hollow cavity depending on the way in which the braiding is performed. The fibre bundles may have been pre-twisted, and one or more fibre bundles may accompany each other.

In the cases where you want a finished product with a round cross-section, a core must be placed in the yarn to fill the hollow cavity. A core consists of fibre bundles with different sizes of twistings.

A braided line without a core will be flattened and have an oval cross-section. Braided lines and ropes are basically neutral and are often preferred for that reason. Braided trawl nets often have no core. There are several reasons for this; it will merely increase the weight without providing increased strength, and the knots are stronger.
From lines to nets

Knotted nets
Machines for net manufacturing have existed for more than 100 years. The first had very limited capacity because they tied the nets in the same way as a net maker would make a net by hand. The modern machines of today have a much greater capacity, i.e. because they tie many knots at once. The spools with the yarns are set up in a number corresponding to the number of rows in the finished net. And here lies one of the most significant limitations in the production. The machines tie the net with weaver's knots, i.e. with the same knot as is used in joints and hand-made nets, but the net exits the machine upside-down, so to speak. The rows are oriented in the same direction as the production direction, and you therefore have to cross-stretch the net when it exits the machine. In this way the width of the machine limits how long the pieces of netting become, while the width of the piece of netting is in principle limitless. Where extra strength is required in the tools, e.g. in the bag of a trawl, the net must be knotted using extra thick lines. This can be difficult if the meshes are small. In such cases the net is usually made of a double or a triple thread. The net will thus be sufficiently strong and retain some of its flexibility. It also makes the net much easier to handle.

In recent years, fishermen have started to use trawl nets in a whole new way. They turn the nets 90° compared to a normal net. This is called T90 and is used mostly in trawl bags and at part of the trawl belly or as intermediate section. When the net is turned in this way it acquires a number of advantages. It is stronger when stressed in this direction, and the meshes are more open. This means that in some trawls the amount of dirt gathered in the trawl bag is reduced and that more small fry are able to escape. In certain trawls the use of T90 nets also benefits the quality of the catch.

Knotless nets
Even though machines for making knotless nets have existed since the 1920s and these types of nets have many immediate benefits, they have only been used in commercial fishing to a limited extent. There are three types of knotless nets: a twisted type, a “crochet” type and a braided type. The twisted type cannot be made with firm knots, and nets of this type are therefore unable to maintain their mesh size. This type is therefore not used in fishing. The crochet net, the so-called Ultra Cross net, is very elastic and is used for fine-meshed...
trawl bags and for sea cages for offshore fish farming. The braided type of knotless nets is patented and is only manufactured two places in the world. It is marketed under the name Ultracross. This type of net is strong because it has no knots and it may offer great savings in trawls as the knots normally contribute significantly to the towing resistance. Unfortunately, it is quite expensive and its use is often limited to small pieces of net inserted as square-meshes in normal trawl nets. Here they act as “windows”, allowing small fry to escape.

**Mesh sizes**

There is some confusion as to how to specify different mesh sizes. There are local traditions, from country to country and from port to port, and there are differences as to what net makers, fishermen and fisheries inspectors “use” the net size for. For example, the net maker uses the mesh size to calculate the length of a piece of netting while the fisheries inspector uses the mesh size to check whether fish of the correct sizes are caught in the net.

You therefore talk about:

*The mesh size in half mesh:* which is the distance from the middle of one knot to the middle of the next. This is the measurement a net maker would use mostly in Denmark i.e. it is the length of a bar or a half mesh. *The mesh size in full mesh:* which is the distance between the middle of two opposite knots in a mesh. This is the internationally adopted way of specifying mesh sizes, and it is used in several of our neighbouring countries, e.g. in Norway and the UK. *Inside measure or the mesh opening:* which is the inside opening between two opposite knots. This is the measurement referred to in the Danish fishing legislation as it says something about the size of fish that are either allowed to escape or are caught.

**Fact Box**

**Legal mesh sizes**

There are a number of legal provisions governing mesh sizes which fishermen must observe. The rules have been introduced as it is deemed inappropriate to catch small fish. Small fish must be allowed to escape through the fishing tools until they are big enough and have had the chance to spawn at least once. In an attempt to take into consideration the different sizes and shapes of fish and crustaceans, different mesh sizes have been introduced in the various fishing tools. In addition to this, the restoration schemes initiated for a number of fish populations in recent years have resulted in further restrictions being imposed. This has resulted in an extensive set of laws that compel fishermen to use different mesh sizes in different trawls and in different waters.

Most net manufacturers produce nets with meshes that are a little larger than the threshold limits set out by the applicable legislation. This provides the fisherman with a small margin which takes into consideration any shrinkage in the net. However, it should be emphasised that the owner of the vessel is responsible to the fisheries inspectors – not the net maker or the net manufacturer.
Rope

The manufacture of rope is based on the same twistings of fibres and yarns used in the manufacture of lines and nets, only with more levels of lays. By varying the number and thickness of the yarns and strands and how hard they are laid, you can make ropes of various dimensions, types and qualities. If the rope is laid from three strands or four strands it is called three-strand or four-strand rope, respectively. An insert (known as the “core”) is always placed in the middle of a four-strand rope to keep the four strands correctly placed in relation to each other.

Most three or four-strand ropes are right-laid. If you twist three hawsers together you get a so-called cable which is normally left-laid.

FACT BOX

Rope maintenance

It is important to handle and look after rope well. Poorly maintained rope can pose a safety risk and does not last very long. In other words, it pays to take care of your lines and ropes. Some good advice:

- Untie knots as soon as possible after using it – leaving knots on the rope will weaken the rope. The breaking strength is reduced by approx. 40 per cent when tying a knot on a line or a rope!
- Do not leave rope and lines exposed to strong sunlight without good reason. Some synthetic ropes (polypropylene) will deteriorate from exposure to sunlight.
- Never haul thick ropes and wires over blocks and discs of a small diameter. When bent excessively, most fibres will be stretched so much that they break.
- Avoid contaminating the rope with acids, alkalis, oils and organic solvents.
- Protect synthetic rope against heat and sparks.
- Remove sand, gravel and oil from rope by washing it in hot water with a detergent.
- Before storing rope, it may be a good idea to wash out the salt water using fresh water.
- Rope is best stored in a cold, dark and dry building which is well-ventilated.
- Examine ropes regularly – look for wear and damage.
- Never step on rope.
- Never leave rope lying loose on the floor. It may be damaged and may cause an accident!
The hardness of the lay determines whether the rope is soft or hard. A lightly laid rope becomes soft and is easy to splice and it does not kink easily, but it does not have the wearing resistance of a hard-laid rope. Braided rope will often consist of several layers of braiding so that the core is also braided. Braided ropes can also be made with several yarns lying next to each other, accompanying each other throughout the braiding. Square-braided rope is solely made of eight strands that accompany each other in pairs. There are four right-laid and four left-laid strands. This type of rope has a natural balance, does not kink and is flexible and easy to handle even when wet. It is therefore one of the preferred types for mooring ropes.

Today, rope – mostly braided – is used in many cases where wire or steel wire rope was previously used. This is often the case in tails and lines in many trawls.

**FACT BOX**

**Dangerous ropes**

When using ropes with a high elasticity for hauling, you put yourself at risk. If the rope breaks, the contraction will fling the rope back against the winch and the object being hauled. At worst, this may result in fatality if there are people in the area. On winches, elastic ropes will build up a contractive force with each turn of the winch. This force may become excessive to the point that the shaft breaks or the flanges are forced out at the sides.

**Wire and combination rope**

Wire is made of iron or steel wires. Iron wires undergo a galvanising process which protects the wire against corrosion while a steel wire is protected in itself. Over time however, both types will be subject to corrosive deterioration. During the manufacture of the wire, mineral fat is added which greases and protects the inner wires.

Wires can be structured in a very complex way. There may be a varying number of strands, but for fishing purposes wire types with six strands are mostly used. The number of wires in each strand may be 6, 7, 12, 19, 24, 26 or 37. The threads in the strands can even be of different thicknesses. Generally you could say that the more threads in a wire, the more flexible it is. Most wires have a core of synthetic fibres. This also adds to their flexibility. In thick wires the strands may have a fibre core.

In Denmark, combination rope is better known as Taifun. This also consists of a combination of steel wire and textile fibres – usually polypropylene – but here the fibres are on the outside. Taifun rope is usually composed with a fibre core on the inside and six strands, all with cores of iron or steel wires.

Wires are to a large extent used as tow wires in trawl fishing and in many other applications where a winch is used for hauling. These applications do not place special requirements on the flexibility, but where the elasticity of the wire must be low. Similarly, combination rope is
used as tails and lines in trawls. Here too, the elasticity of the wire must be low. Wire and combination rope with threads of steel are more expensive than galvanised iron and is therefore only used where special conditions make it necessary. For example, Taifun with steel wires is used in small trawls which are only used for a short season and which are therefore expected to last for many years.

**Trawl drawings, specification of net types**
The net maker’s drawing should specify how the tool is made and the materials used. The drawing must therefore include the following information:

- The raw material used to make the net
- Type and dimension of the yarn
- The mesh size
- Width and length of each net section

Unfortunately, no international agreements have been made to determine these specifications. The subsequent overview is, however, based on the Danish standard terms, and only in cases where it has been deemed absolutely necessary have other terms been included. The synthetic material is only specified directly in a few cases. Normally, this is only stated as some form of number code in connection with the specification of the yarn type and thickness.

**Polyamide**: twisted net is only specified by its yarn number which expresses the net thickness. Braided net is specified by the line diameter. The international term is “210/yarn number”. The international yarn number is three times the Danish number as we specify the number of yarns in a strand, while the international yarn number specifies the number of yarns in the entire line.

**Polyester**: twisted net is specified by the yarn number followed by the number 3, and braided net again by its diameter. Internationally by a “250/yarn number” (three times higher than the Danish number).

**Polyethylene**: twisted net is specified by a “3/yarn number”, braided net by its diameter and internationally by a “500/yarn number” (three the Danish number). Braided lines are normally just specified by their diameter and you therefore have to specify the material in more detail. Furthermore, the diameter is not a measurement in itself, as these lines are often flattened, it is how the lines used to be measured.

**Fact Box**

Examples of terms for nets as specified on the net maker’s drawings

<table>
<thead>
<tr>
<th>Twisted materials</th>
<th>Braided materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyamide No. 20 or 210/60</td>
<td>4 mm braided nylon</td>
</tr>
<tr>
<td>Polyester 203 or 250/60</td>
<td>PES br. 4.0 mm</td>
</tr>
<tr>
<td>Polyethylene 3/20 or 500/60</td>
<td>br. PES 4.0 mm</td>
</tr>
<tr>
<td></td>
<td>br. PET 4 mm</td>
</tr>
<tr>
<td></td>
<td>br. nylon 4.0 DB</td>
</tr>
<tr>
<td></td>
<td>Rope-laid 240 TS</td>
</tr>
<tr>
<td></td>
<td>Net turned 90° T90</td>
</tr>
<tr>
<td></td>
<td>Double thread DB 4mm</td>
</tr>
</tbody>
</table>
A different number of letters may be added to these number specifications, specifying that the net is made from a double thread: DB, or that the thread is rope-laid: TS. This means that each yarn includes three lays. This is only used in very thick yarns. T90 specifies that the net must be turned 90°.

As mentioned above, Danish net makers specify the mesh size as the half mesh size while the numbers used by the fishing legislation are the inside measure or the mesh opening. In most cases, net manufacturers try to adapt their products to the applicable legislation so that there is a certain margin, allowing the net to shrink.

The number of meshes in the depth of a piece of netting is determined by the width of the machine making the net. In many cases the mesh depth will be a half mesh from a round number, e.g. 49.5 or 99.5 meshes. This way the finished net section in the tool will be 50 or 100 meshes with the lacing.

The width of a net section is specified by the number of knots in a certain row across a net. The number of knots will be double the number of meshes.

**Properties**

To be able to select the correct material for a certain part of a tool you must know the properties of the materials. Their breaking strength, elasticity, pliability, density and a number of other properties which must be weighed up against each other – and, of course, against the price.

It is difficult to comment in general on the properties of a net or rope material as they vary from manufacturer to manufacturer. The actual raw material has a number of reasonably well-defined properties, but they can be strengthened or weakened by the way in which the thread is twisted, braided or knotted into a net or a rope and by the way that the manufacturers finish the nets in terms of stretching, treatment/heat treatment, etc.

In the following section we will review the various properties which the net maker must consider when selecting materials for a fishing tool.

**Durability in water**

Even though some of the material properties are altered by being submerged in water, they are not weakened. Synthetic materials can last almost infinitely in water. It is only nylon (PA) which can absorb water, and the properties of this material are thus most liable to changes depending on whether it is wet or dry.

**Weather resistance**

It is very difficult to determine the durability of a synthetic material in air. Of course, many factors come into play and make the material brittle. There is, however, no doubt that the most significant factor is the effect from the ultraviolet rays of sunlight. With untreated materials, the breaking strength is reduced by 50 per cent following long-term exposure to sunlight. Polypropylene (PP) appears to be have the lowest durability while polyester (PES) is the most durable. Polyamide (PA) and polyethylene (PET) lie in between.
The treatment process often involves adding a substance which prevents sunlight from penetrating the material. The treated materials therefore only lose 5-10 per cent of their breaking strength, even after long-term exposure to sunlight.

However, the conclusion is that you should cover your net, and as the net does not rot it will not be damaged by being wet.

Density

Density is one of the properties which you can literally touch and feel. The density of all plastic materials is close to that of water, but it is important to know whether it is above or below, as this determines whether the material sinks or floats. Density is normally expressed in grams per cubic centimetre. The density of fresh water is 1.00 g/cm³. That of saltwater in the open sea is 1.02 g/cm³.

Polyamide and polyester are heavier than water while polyethylene and polypropylene float. These data are important for the fisherman to know when mounting weights and floats on a fishing tool. This is particularly important when a mooring line or another rope runs around a mooring post. This may produce a significant amount of heat.

Properties of the finished net or rope

As mentioned earlier, the post-treatment of the raw materials will affect a number of important properties. Fibre type, dyeing, twisting, knotting, treatment and stretching will all determine the applications of the finished net or rope. The quality assurance of the manufacturer is also a significant factor. It is therefore very difficult to provide specific information about the properties. In the following we will thus have to stick to certain general features, knowing that there may be net and rope types that do not fall into this category.

Breaking strength

The breaking strength is understandably one of the most important properties that the fisherman and the net maker must consider when selecting a material for a certain job. You have to weigh both the safety of
having a material which will be sufficiently strong against the price, the weight and the towing resistance of a strong piece of netting or rope.

Most manufacturers specify the breaking strength of a dry line – also in connection with nets. But this value is useless for the fisherman as he needs to know the breaking strength of the wet, knotted net which will typically be considerably lower. The reason for this is that once a knot is tied on a line or rope, its breaking strength will be reduced by approximately 50 per cent in most materials. In nets the knot breaking strength is thus much more important to know than the breaking strength.

Generally, the breaking strength for a dry line is very high in the four most common materials, and somewhat higher for nylon and polypropylene than for polyester and polyethylene. But when comparing the knot breaking strength for the same materials, it becomes evident that polyethylene does not lose its breaking strength to the same extent as the others. Thus, the material compensates for its somewhat lower breaking strength when dry.

**Knot firmness**
In nets that are subjected to heavy stress, such as trawl net, it is important that the knots do not slide. Knot firmness is thus an important property in ensuring that the trawl does not lose its shape.
In net fishing it is also unfortunate if the mesh loses its shape due to knot sliding. Good knot firmness depends partly on the material, the fibre type and the twisting. It can be increased by finishing the net by hot stretching or by impregnating the material in a treatment process.

**Stretching**
The stretching of a material covers several different aspects:

- Shock resistance capability
- The stretching at a certain load, e.g. 50 per cent of the knot breaking strength
- The reaction to long-term constant load
- The ability to regain its original length following a certain amount of stress

When the material is capable of stretching when subjected to stress, it is more capable of absorbing shock effects without breaking, and it can distribute the pull more evenly in the net.

The stretching of a material depends heavily on the fibre type and the twisting of the thread, and there are therefore large variations from manufacturer to manufacturer. Thus, staple fibres not only have a lower breaking strength, they also lead to increased stretching than continuous fibres.
In general, the stretching is higher in nets made of polyamide (PA) than in other raw materials. At 50 per cent knot breaking strength, a large-scale examination of different materials showed that the stretching in polyamide (PA) was 15-30 per cent and 10-15 per cent in polyester (PES), polyethylene (PET) and polypropylene (PP).

One of the most important properties associated with stretching is the ability of a material to regain its original length. This is called elasticity. If the net has complete elasticity the net will not only retain its shape, but also its mesh width. However, a certain amount of sustained stress will often result in some degree permanent stretching.

**Flexibility**
The rigidity or the flexibility of a material for a fishing tool is usually not that significant within the normal framework. Furthermore, there are some tools, e.g. certain types of net in which a high rigidity is not desirable. A rigid net can be easier to handle, clean and repair whereas a flexible rope can be easier to coil.
A number of the treatment agents used for net protection increase the rigidity of the material.

**Wearing resistance**

Before the introduction of synthetic materials for fishing tools, the wearing resistance of the material was virtually without significance as the material always rotted away before it was worn out. Today, things are quite different in this respect. The durability of a net or a rope depends entirely on the wearing resistance of the material. The highest degree of wear appears to occur on board the vessel where the material rubs against rollers, pipes, hull etc. On stern trawlers a high degree of wear occurs when the bag is hauled up through the ramp.

The wear occurring while the tool is being used for fishing is a problem in bottom trawling and seining. Sand, gravel and rocks will result in a lot of wear, but in most cases many efforts have been made in the construction of the tool to avoid that the tool comes into contact with the sea bed. The highest degree of wear occurs in the knots of the net. Furthermore, on rope you often see wear produced by the fibres rubbing against each other.

It is difficult to compare studies of the wearing resistance of different materials. However, it seems that the coarser the material, the higher the wear. Thus, staple fibre lines will wear faster than continuous fibre lines. Similarly, it seems that the higher the strength of the individual fibres, the higher the wear resistance. The monofilaments are thus the most durable lines, particularly if they are made of nylon (PA).

**Shrinkage**

It was previously mentioned how nets made of PA in some cases shrink when exposed to water for the first time. It is very important for a net maker and a fisherman to know the extent of this phenomenon before using the material for, e.g., trawl bags, where the mesh width is stipulated in the fishing legislation.

Naturally, fishermen are not interested in using meshes with a large safety margin in relation to the legal mesh width. The choice of mesh width in a trawl bag will therefore often be a balancing act.

However, the effect of the water on the material is not the only factor which is able to change the mesh size. Sometimes a trawl bag will have absorbed a lot of sand in its bars and knots. This is particularly the case with braided nets and nets made of heavy-duty material. In addition to significantly increasing wear on the net, it will also lead to the bars getting thicker and thereby shorter. You could call this sand shrinkage.

Another aspect which may reduce the effective mesh size is when the material is exposed to a pull of such a magnitude that some of the fibres break. The line will obtain a woollen appearance, and the bars will get thicker – and again shorter.