Fishing gear materials: classification, properties & advancements

Sandhya K. M*. & Saly N. Thomas

ICAR-Central Institute of Fisheries Technology, Cochin, Kerala-682029
*sandhyafrm@gmail.com

Introduction

Netting materials for fabrication of fishing gear are either of textile or non-textile origin. The raw material for fish netting consists of fibres which can be distinguished into two groups: natural fibres and man-made fibres. Different kinds of fibres originating from plant and animal body parts have been used for production of textiles and other products are termed as natural fibres. Traditional fishing gears used earlier, till 1950s were mainly with natural fibres such as cotton, manila, sisal, jute and coir. Man-made fibres constitute natural polymers and synthetic polymer. Natural polymers are manufactured by the alteration of natural polymers like cellulose and protein while synthetic polymers are obtained by synthesis or chemical process. Man-made fibres derived from cellulose eg: rayon, are susceptible to microbial deterioration while synthetic fibres are very resistant to biodeterioration. In the late 1950s, with the introduction of man-made synthetic fibres, natural fibres used for the fishing gears have been substituted by these synthetic materials. This transition was mainly due to the highly positive properties of these fibres such as highly non-biodegradable nature, high breaking strength, better uniformity in characteristics, high abrasion resistance, low maintenance cost and long service life.

Synthetic fibres

Synthetic fibres are produced entirely by chemical process or synthesis from simple basic substances such as phenol, benzene, acetylene etc. The chemical process involves the production of macromolecular compounds by polycondensation or polymerization of simple molecules of a monomer. The raw materials are petroleum, coal, coke and hydrocarbon. Depending on the type of polymer, synthetic fibres are classified into different groups and are known by different names in different countries. Altogether seven groups of polymers are developed; most important polymer/synthetic fibres used in fishing gears are polyamide (PA), polyester (PES), polyethylene (PE) and polypropylene (PP). Other synthetic fibres, which are less widely used and generally restricted to Japanese fisheries, are polyvinyl alcohol (PVA), polyvinyl chloride (PVC) and polyvinylidene chloride (PVD). Aramid fibres, Ultra high molecular weight polyethylene (UHMWPE) and liquid crystal polymer are later additions to this group.

***Polyamide (PA)*:** Polyamide, a synthetic polymer, popularly known as nylon, invented in 1935 refers to a family of polymers called linear polyamides. Nylon consists of repeating units of amide with peptide linkages between them. Depending on the raw material and method of making two types of nylon viz., PA 6 and PA 66 are available for fibre applications. PA 66, widely used for fibres is made from adipic acid and hexamethylene diamine while PA 6 is built with caprolactam. With regard to the fisheries, there is no difference between PA 66 and PA 6, while in India, for fishing purposes PA 6 is used. The softness, lightness, elastic recovery, stretchability and high abrasion and temperature resistance are superior properties inherent to nylon. However, high moisture absorption along with dimensional instability and requirement of UV stabilization are its disadvantages. On wetting, nylon loses up to 30% of tensile strength and 50% of tensile modulus.

Polyolefines: Polypropylene (PP) and Polyethylene (PE) are often collectively called "polyolefines". Polyolefin fibres are long-chain polymers composed (at least 85% by weight) of ethylene, propylene or other olefin units. Polyolefin fibres are made by melt spinning. They do not absorb moisture and have a high resistance to UV degradation.

***Polyethylene* (PE):** PE fibre is defined as: "fibres composed of linear macromolecules made up of saturated aliphatic hydrocarbons". PE fibres, used for fishing gear, are produced by a method developed by Ziegler, in the early 1950s.The monomer ethylene, the basic substance of polyethylene, is normally obtained by cracking petroleum. Linear polyethylene or high-density polyethylene has high crystallinity, melting temperature, hardness and tensile strength. In India, PE is used for manufacture of netting and ropes.

***Polypropylene* (PP):** PP fibre is defined as: "fibres composed of linear macromolecules made up of saturated aliphatic carbon units in which one carbon atom in two carries a methyl side group". This is an additive polymer of propylene. PP was commercialized in 1956 by polymerizing propylene using catalysis. Though PP netting and ropes are available, in India, PP is mainly used for ropes.

***Polyester* (PES):** The principal PES fibres are made from polymerization of terepthalic acid and ethylene alcohol. It was first synthesized by Whinfield and Dickson of Great Britain in 1940-41 and named the fibre "Terylene".

Recent advances in synthetic fibres

Introduction of synthetic materials with high tensile strength properties has made it possible to bring out changes in the design and size of fishing nets. As the fishing industry became highly competitive, the search and research for new generation materials which give better strength for less thickness resulted in invention of new materials. Aramid fibres, Kevlar, UHMWPE, biodegradable plastic etc are recent introductions to the fishing gear material sector. These materials have advantages, especially less drag which results in fuel efficiency. The performance of UHMWPE webbing and rope in the Indian context is being studied by ICAR-CIFT. Among the new fibre types, only Sapphire and UHMWPE are used on a commercial basis for fishing gear viz., trawls and purse seines in Australia and Alaskan waters. Sapphire is also used on a limited scale in large mesh gillnets targeting large pelagics in Maharashtra region of India.

Aramid fibres: Aramid fibres are fibres in which the base material is a long-chain synthetic polyamide in which at least 85% of the amide linkages are attached directly to two aromatic rings. Two types of aramid fibres are produced by the DuPont Company: Kevlar (para-aramid) and Nomex (meta-aramid), which differ primarily in the substitution positions on the aromatic ring. Generally, aramid fibres have medium to very high tensile strength, medium to low elongation-to-break, and moderate to very high modulus.

KEVLAR® polyphenylene terephthalamide (PPTA): A polymer containing aromatic and amide molecular groups is one of the most important man-made organic fibre ever developed.

Because of its unique combination of properties, KEVLAR® is used in the fishing sector as netting, fishing rod and fishing line. Fibres of KEVLAR® consist of long molecular chains produced from poly (p-phenylene terephthalamide). The chains are highly oriented with strong interchain bonding, which result in a unique combination of properties. The strength to weight ratio of Kevlar is high; on a weight basis, it is five times as strong as steel and ten times as strong as aluminum. It has high tensile strength at low weight, low elongation to break, high toughness (work-to-break), and excellent dimensional stability. In sea water, ropes with KEVLAR® are upto 95% lighter than steel ropes of comparable strength.

Ultra high molecular weight polyethylene(UHMWPE): UHMWPE is a type of polyolefin synthesized from monomer of ethylene processed by different methods such as compression molding, ram extrusion, gel spinning, and sintering. Polyethylene with an ultra high molecular weight (UHMWPE) is used as the starting material. In normal polyethylene, the molecules are not orientated and are easily torn apart. The fibres made by gel spinning have a high degree of molecular orientation with very high tensile strength. The fibre is made up of extremely long chains of polyethylene, which attains a parallel orientation > 95% and a level of crystallinity of up to 85%. The extremely long chains have molecular weight usually between 3.1 and 5.67 million while HDPE molecule has only 700 to 1,800 monomer units per molecule.

UHMWPE, also known as high modulus polyethylene (HMPE) or high performance polyethylene (HPPE) is a thermoplastic. It has extremely low moisture absorption, very low coefficient of friction, is self-lubricating and is highly resistant to abrasion (10 times more resistant to abrasion than carbon steel). This is available as Dyneema and Spectra produced by two different companies. Commercial grades of dyneema fibres SK 60 and SK 75 are specially designed for ropes, cordage, fisheries and textile applications

UHMWPE is 15 times stronger than steel and up to 40% stronger than Kevlar. UHMWPE netting is 3 times stronger than nylon with the same dimension, and increases the net's strength while the abrasion resistance increases the net's life. Netting can be used for trawl nets, purse seine nets and aquaculture nets. Nylon purse seines last for about 2-3 years while UHMWPE netting ensures 2-3 times more life for the net. The netting twines made with dyneema fibre can be reduced by upto a factor of 2 on thickness (diameter basis) and on weight basis by a factor of 4. This allows fishing vessels to increase their catch potentially by as much as 80% by trawling faster or using larger nets, or to reduce fuel consumption. Besides, less deck space is required due to lower bulk volume of the net. Purse seines made of dyneema would facilitate 40% increase in sinking speed due to better filtering and reduced drag. Larger net for the same weight can be made. The net has better durability with negligible wear & tear.

Ropes made from UHMWPE have a higher breaking strength than that of steel wire ropes of the same thickness, but have only one-tenth the weight. Fishing uses for these high-strength polyethylene ropes include warp lines, bridles and headlines. By using UHMWPE ropes, the frequent oiling & greasing required for wire ropes can be avoided which would facilitate a clean and safe deck and free the crew from greasing the rope frequently. It also helps in a clean catch devoid of oil and grease contamination.

Liquid Crystal Polymer Fibre: Vectran®, a high-performance thermoplastic multifilament yarn spun from Vectra® liquid crystal polymer (LCP), is the only commercially available melt-spun LCP Fibre in the world. Vectran fibre is five times stronger than steel and 10 times stronger than aluminum. Vectran fibre is 4 times stronger than polyethylene fibre or nylon fibre. The unique properties that characterize Vectran fibre include: high strength and modulus; high abrasion resistance; minimal moisture absorption; and high impact resistance. Although Vectran is lacking UV resistance, this limitation can be overcome by using polyester as a protective covering. It is very suitable for trawl nets and ropes.

Fluorocarbon fibre: Fluorocarbon fibre is a new material that can be used in angling and high-speed jigging lines. It has very high knot strength, almost invisible in water, has high breaking strength and abrasion resistance.

Sapphire: Sapphire PE netting manufactured from specialized polymers available in twisted and braided form is suitable for trawl nets and for cage culture. It has the highest knot breaking strength, knot stability and dimensional uniformity. Braided twine having compact construction restricts mud penetration and provides lesser drag. Sapphire is used on a limited scale for fabrication of large mesh gillnets targeting large pelagics in Maharashtra region of India. Sapphire ultracore is a knotless HDPE star netting with an outer layer of heavier sapphire ultracore which features strands of marine grade stainless steel as an integral part of the netting twine. The stiffness and cut resistance enable it to be used as a predator protection net cum cage bag net where the predation problem is very high.

Basic terms in netting

Fibre: the basic material of netting, has length at least 100 times its diameter.

Netting yarn: is the standardized universal term for all textile material which is suitable for manufacture of netting for fishing gears and which can be knitted into netting by machine or by hand without having to undergo further process. Yarn is made into a netting by twisting or braiding. Monofilaments are used directly for making into netting without further process.

Netting twine:or folded yarn is a netting yarn which is made of two or more single yarns or monofilaments.

Cabled netting twine: Combines two or more netting twines by one or two further twisting operations. Fibres are combined to form single yarns. Several single yarns are twisted together to form a netting twine. Several of these folded yarns or netting twines are twisted together by a secondary twisting operation to form a cabled netting twine.

Braided netting yarns: These are produced by interlacing a number of strands in such a way that they cross each other in diagonal direction. These braids are usually in the form of tubes. The braided netting yarns are available with or without core. Core is the term used for single yarn, twisted yarn or monofilaments which do not belong to the braided tube but fills the space inside the tube.

Netting: Netting is defined by International Organization for Standardization (ISO) as a meshed structure of indefinite shape & size, composed of one yarn or one or more systems of yarns inter laced or joined or obtained by other means for example by stamping or cutting from sheet material or by extrusion

Basic yarn types: Fibre is the basic material used for the fabrication of netting yarns. By twisting, braiding or plating, yarns are made into twine. For twine construction, there are two steps, first is the twisting together of two or more single yarns to form a strand/ply and the second step involves the twisting together of two or more strands to form a twine. The basic forms in which most synthetic fibres are produced are continuous filaments (multifilaments), staple fibres, monofilaments and split fibres. Continuous filaments are fibres of indefinite length. A quantity of continuous filaments is gathered up, with or without twist to form a filament yarn termed as multifilament. Staple fibres are discontinuous fibres, prepared by cutting filaments into short lengths usually 40-120 mm suitable for the yarn spinning fibres. Staple fibres are twisted to form a spun yarn. These have a rough surface due to the numerous loose ends of fibres sticking out from the twine. Monofilament is a single yarn strong enough to function alone as a yarn without having to undergo further processing. Unlike fine continuous filaments and staple fibres, this can be directly used as individual fibres for netting. Split fibres, developed from oriented plastic tapes (flat tape) which are stretched during manufacture at a very high draw ratio resulting in the tapes splitting longitudinally when twisted under tension.

Types of synthetic yarns for fishing

PA is available as multifilaments, staple and monofilaments yarn. PE is available as monofilaments (twisted) but not as staple fibres or as multifilaments while split fibres are not common. In the case of PP, fibres as multifilaments, split fibres and monofilaments for ropes are available. PES is available only as multifilament fibres and not as split fibres. The synthetic netting yarns used in Indian fishing sector are PA, PE and PP. PA and PE are the most commonly used fibres for netting while PP and PE are used for ropes. Of these, PA is mostly used in gillnets, line and purse seine sector while PE is used in the trawl net sector and to a less extent in deep-sea gillnet sector.

Nylon multifilament nettings are available as knotless and knotted while nylon monofilament nettings are available as knotted only. Nylon multifilament nettings are commonly used for the fabrication of various types of gillnets, ring seine, purse seine, cast net, Chinese nets, drift nets etc. Common specifications of nylon multifilament twine for fishing ranges from 210x1x2 to 210x12x3. The mesh size commonly required ranges from 8 mm to 450 mm for different fishing gear. It is more effective for fishing than polyester because of the better sinking speed and extensibility. Nylon monofilament is better for long lining and various types of gillnetting. The twine range for fishing purpose is from 0.10 to 0.50 mm dia and for long line fishing 1.5 to 3 mm.

HDPE twine is of two types; braided and twisted. Twisted twine is available normally in the range of 0.25 to 3.00 mm dia while braided twine is available in the range of 1.0 to 3.0 mm dia. HDPE netting is mainly used for fabrication of trawl nets.

Designation of yarn: Monofilament yarn is usually designated by diameter. Multifilament twisted twines are designated by runnage (length of twine against a standard weight) or by designation, viz., the yarn size, number of yarns in the strand, and number of strands in the twine.

Example: 200x4x6; indicates that the yarn size is 200 denier, 4 yarns in one strand and 6 such strands are twisted together to form the twine.

Yarn numbering system

For designation of the size of the yarn, a `yarn numbering system' is developed. The size of the yarn is given by yarn numbering system which is based on the length-weight relationship of the yarn. There are two types of yarn numbering systems, viz., direct and indirect.

1. ***Direct System:*** In this system, the weight of the yarn against a standard length is taken. For example the length of yarn is kept constant and the weight changes.

i. Denier

9000 m of yarn weighing 1 g is 1 denier

9000 m of yarn weighing 210 g is 210 denier

ii. Tex: This is the internationally accepted system of numbering for all textile yarns.

1000 m of yarn weighing 1 g is 1 tex.

1000 m of yarn weighing 20 g is 20 tex

2. ***Indirect system:*** Here the length of yarn for a standard weight gives the yarn number or the weight is kept constant and the length varies.

i. British Count (Ne)

840 yards weighing 1lb is 1 Ne

20x840 yards weighing 1 lb is 20 Ne

This is commonly used for cotton and synthetic staple yarns.

ii. Metric Count (Nm)

1000 m of yarn weighing 1 kg is 1 Nm

20x1000 m of yarn weighing 1 kg is 20 Nm.

In the direct system of numbering the more the yarn number, the thicker the yarn would be and in the indirect system the more the yarn number, the finer the yarn would be.

For conversion from one system to another, the following conversion formula is used.

$$Tex = \frac{590.5}{Ne} = \frac{1000}{Nm} = \frac{100000}{m/kg} = \frac{496055}{yds/lb} = 0.11 \text{ denier}$$

Identification of synthetic fibres

Identification of synthetic fibres by appearance alone is not easy and correct. Different groups of synthetic fibres can be identified by various methods.

Water test

Identification of synthetic fibres can be started with this test. In a short piece of netting yarn, tie a simple overhand knot and put the piece into a vessel filled with water. Air bubbles in the material must be squeezed out by hand underwater. Based on water test, netting materials can be classified into two groups; (1) synthetic fibres which float in water (PE & PP) (2) fibres which sink (all other synthetic fibres).

Burning test

In the burning test, the nature of burning and smoke in the flame as well as after leaving the flame are observed. The netting material can be brought near to the flame and after removal from the flame, observe the smell of smoke and the residue. Synthetic fibres shrink and melt in the flame, the melting substance drips from the flame mostly forming a bead or a hard irregular residue. The changes in different synthetic fibres during burning test is given in table

Table 1. Burning characteristics of synthetic fibres

Material	**PA**	**PES**	**PE**	**PP**
In flame	Melts, burns with light flame, white smoke, melting drops fall down.	Melts, burns with light flame, sooty black smoke, melting drops fall down.	Shrinks, curls, melts and burns with light flame, drops of melting fall down.	Shrinks, melts and burns with light flame melting drops fall down.
After leaving the flame	Stops burning, melting drops can be stretched into fine thread.	Stops burning, melting bead may be stretch into fine thread.	Continues to burn rapidly, hot melting substance cannot be stretched.	Continues to burn slowly, hot melting substance can be stretched.

Solubility test

Solubility test is a relatively simple chemical test. Fibres of the sample to be tested should be in a loose form. The netting yarn must be untwisted and the fibres can be cut into small pieces of 1cm length. Coarse material like split fibres and especially monofilaments should be cut to very small pieces. Take 10-15ml of the solvent into the test tube and put the sample pieces into it. The results of the reactions are shown in table 2.

Table 2. Identification of synthetic fibres by solubility test

Reagent	**Type of fibre**			
	PA 6	**PES**	**PE**	**PP**
Hydrochloric acid/HCL (37%) 30 minutes at room temperature	+	**o**	**o**	**o**
Sulphuric acid/H_2SO_4 (97-98%) 30 minutes at room temperature	+	+	**o**	**o**
(1) Dimethylformamide/HCON $(CH_3)_2$ 5 minutes boiling	+	+	**o (2)**	**o (2)**

Formic acid/HCOOH (96-100%) 30 minutes at room temperature	+	**o**	**o**	**o**
Glacial acetic acid/CH_3-COOH 5 minutes boiling	+	**o**	**o**	**o**
Xylene/C_6H_4 $(CH_3)_2$ 5 minutes boiling (inflammable)	**o**	**o**	+	+
Pyridine 30 minutes at room temperature	**o**	**o**	**o**	**o**

+ = soluble, o = not soluble, (1) = Dimethylformamide is decomposed by exposure to light even when stored in a brown bottle, needs to be stored away from light preferably in a cool place, (2) Destroyed but not soluble

Properties

As far as the fishing gear purpose is concerned, properties which are of importance are linear density, diameter, specific gravity, knot stability, breaking load, elongation, weathering resistance and abrasion resistance.

Diameter: The diameter of netting material is an important factor influencing the fishing gear performance. Thickness and rigidity of the material influences the resistance of fishing gear to water flow and hence the power required or the speed obtained in towing gears are depended on it. Thinner twines offer less resistance. Diameter of a material is dependent on the type of polymer, type of yarn, size of yarn, specification and construction. Diameter is expressed in mm and is measured using a travelling microscope or a micrometer.

Linear density: It is the mass per unit length of the material. The mass in g of 1000 m length of a material is expressed as R tex and mass of 9000 m of the material as R denier. While comparing different types of yarns, the Rtex values serve as a relative measure for the mass of netting. For the same kind of material, lower Rtex means thinner material and generally costs less while buying on a mass basis.

Specific Gravity:Specific gravity of most of the synthetic fibres is less than the natural fibres. Specific gravity influences the fishing gear as fibres with lesser specific gravity allows a greater length of netting for a given weight of yarn and helps in savings in handling and power. However, for a gear such as purse seine, material with very low specific gravity is not the suitable one as quick sinking of the net is a prime requisite to capture a shoal of fish.

Twist: The number of turns or twists imparted to a twine per unit length is important as it influences many properties especially the breaking strength, diameter, linear density, resistance to abrasion and general wear and tear of the twine. As the amount of twist increases the breaking strength also increases upto a critical degree of twist beyond which it would weaken the twine. The stability of a twine depends on the correct amount of twists per unit length. The twine has an inner/strand/primary twist and outer/secondary/twine twist. Balance between these two twists ie: primary twist for making strands from yarns and secondary twist to make twine from strands is important. Twines with a well balanced twist do not have a tendency to snarl.

Breaking strength and elongation: The breaking strength/load of a material denotes the ability of a material to withstand the strain. It depends on the type of polymer, type of yarn, degree of twist and thickness of the material. Tenacity is the breaking load in terms of yarn denier while tensile strength is the force in terms of unit area of cross section. The strength of fibre changes in the wet condition; in natural fibres the wet strength is higher while the reverse is true of synthetic fibres. Knotting also causes reduction in the breaking strength. This is dependent on the type of polymer, type of yarn and knot, twine construction and also on the degree of stretching. Breaking load is expressed in Newton (N).

Elongation is the increase in the length of a specimen during a tensile test and is expressed mostly in percentage of the nominal gauge length. Extensibility is the ability of a netting material to change its dimension under a tensile force. It involves a reversible and an irreversible elongation. Irreversible or permanent elongation is the part of the total increase in length which remains after the removal of the stress. Reversible or elastic elongation is the part of the total increase in length which is cancelled again, either immediately or after a long period of removal of stress.

Weathering Resistance: Even though all fibres, irrespective of natural or synthetic are prone to degradation on exposure to weathering, the problem is severe with synthetic fibres. The effect of weathering depends on the thickness of yarn, as thicker twines show better resistance. This is because the layers below are protected by the degraded outer layers and generally UV rays do not penetrate more than 1mm. By dyeing the weathering resistance can be improved. PVC has very high resistance against weathering, while PES has high and PA and PE, have medium resistance against weathering. Among different types of fibres, monofilament form is more resistant than multifilament and staple yarn.

Abrasion Resistance: The resistance of netting materials to abrasion, ie, abrasion with hard substances such as boat hull, sea bottom and net haulers, or abrasion between yarns/twines is important in determining the life of a net. The resistance to abrasion depends on the type of fibre, thickness and construction of the material. Polyamide has the maximum abrasion resistance, followed by PP, PES and PVC. The better abrasion resistance of PA is due to the inherent toughness, natural pliability, and its ability to undergo a high degree of flexing without breakdown. Among different types of materials, monofilament is better than multifilament, and between staple and multifilament, the latter is better. Abrasion can cause rupture of the material as also reduction of mesh size due to the internal abrasion caused by the friction of the fibres against each other.

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