Netting Materials for Fishing Gear with Special Reference to Resource Conservation and Energy Saving

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Introduction

Netting yarns/twines forms the main part of majority of fishing gears. Apart from giving structure and shape to the gear, materials play a substantial role in resource and energy conservation. Netting materials for fabrication of fishing gear are either of textile or non-textile origin. Textile materials comprise of netting, twine and rope while floats, sinkers, hooks etc constitute non-textile origin materials. 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.

Like elsewhere in the world, in India too, with the introduction of man-made synthetic fibres in the late 1950s, 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. Earlier, nettings used to be fabricated manually, which is laborious and time consuming while the introduction of synthetic fibres paved way for machine made nettings which revolutionized the fishing industry.

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

Natural Fibres: Fibres of plant origin such as that of cotton, manila, sisal, hemp, linen, ramie, coir etc. and of animal origin such as silk, hair etc are termed as natural fibres. As far as the fishing industry is concerned, the plant/vegetable fibres are better suited for the fabrication of fishing gear than animal fibres which are too expensive. Based on the source of origin, vegetable fibres come as seed fibre, fruit fibre, leaf fibre and bast fibre. Seed fibre is available from cotton (*Gossipium* sp.) while coir (*Cocos nucifera*) is a source of fruit fibre. Sisal (*Agave sisalana*), Abaca/Manila (*Musa textiles*) and pineapple leaf (*Ananas comosus*) are sources of leaf fibre. Examples of bastfibres are True hemp (*Cannabis sativa*), Indian hemp (*Crotalaria juncea*) and jute (*Corchorus capsularis*).

While eco-friendliness and reasonable weather resistance are positive attributes for natural fibres, the high biodegradability (being cellulose in origin) and very short useful life time, when exposed to water, are negative attributes of natural fibres. To increase the service life, frequent preservation and protection measures are required which limit the effective and continued use of natural fibres in different fishing seasons. Moreover, on wetting, natural fibres absorb water and swell resulting in increased thickness, bulkiness and weight which limit the size of gear that can be handled from a boat.

Man-made fibres: Natural polymers and synthetic polymers constitute man-made fibres. 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.

Synthetic fibres have greatly extended the endurance of fishing gears, and together with mechanized vessels, have increased the size and complexity of nets. It is stated that synthetic fibres brought to one of man's oldest occupations, the miracle of science and in doing so provide easier living for the fishers. The development of synthetic fibre was based on the discovery that all fibre materials consist of long chain molecules in which a great number of equal simple units are linked together. This structure gives the fibre the properties required for a textile fibre. 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 (PVAA), 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".

Later introductions

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.

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. It can be made into microfilament braided twine of fine diameter. Nettings of simple knot, double knot and knotless are available. A comparison of properties of UHMWPE to other synthetic fibres is given in Table 1.

Table 1. Comparative properties of synthetic fibres

Chemical/physical characteristics	Fibre					
	PA 6	**PA 66**	**PES**	**PP**	**PE**	**Dyneema SK75**
Tenacity (g/den)	9	9	9	7	5	40
Elongation at break (%)	23	20	14	18	20	3.5
UV rays resistance	medium	weak	medium	medium	medium	good
Specific weight	1.14	1.14	1.38	0.91	0.97	0.97
Resistance to alkalis	good	good	weak	good	good	good
Acid resistance	weak	weak	good	good	good	good
Moisture absorption% (65%-20°C)	3.5-4.5	3.4-4.5	0.2-0.5	0	0	0

(Source: Badinotti, 2011)

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. Vectranfibre 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. Physical properties of Vectran yarn in comparison with the others which has similar diameter are given in Table 2.

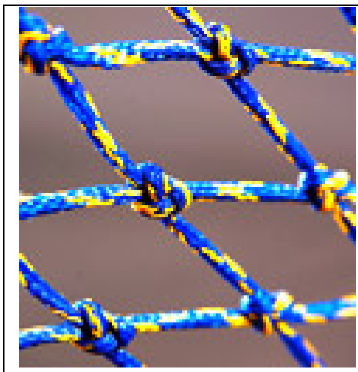
Table 2. Comparative properties of Vectran yarn with other yarns

Properties	Vectran	UHMWPE	Regular polyethylene	Regular polyamide (nylon6)
Size (denier)	9000	4800	7200	7560
Diameter (mm)	1.31	1.13	1.47	1.26
Weight (g/m)	1.1	0.6	0.89	0.94
Tenacity(wet) *1 (kg)	148	85	35	46
Elongation at break(wet) (%)	9.4	11.2	28.4	41.3
Elongation at break(dry) (%)	9	10.6	32.6	36.7
Resistance for abrasion (wet, 1kg load) *4 (times)	421	295	73	61
Resistance for abrasion (dry, 1kg load) *5 (times)	55	15	-	13

Source: http://www.nagaura.co.jp/english/bect.html

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.

		
Sapphire Ultracore	Kevlar	UHMWPE

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.

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.

Probable Yarn types in each polymer group

All fibre types from all the seven chemical groups are not available/suitable as netting yarns. 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.

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

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.

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

Identification of synthetic fibres

Identification of synthetic fibres by appearance alone is not easy and correct. Different physical and chemical test methods are employed to identify groups of synthetic fibres.

Specific gravity: Important fibres can be segregated by differences in specific gravities, which are listed below. Air trapped is to be completely removed from the yarn or fibre bundle before determining the specific gravity.

PA :1.14; PE: 0.96; PP: 0.91; PES: 1.38

PE and PP fibres float while other fibres sink in water.

Burning test: In the burning test, the nature of burning and smoke in the flame as well as after leaving the flame are considered as detailed in Table 1.

Table 1. Identification of different polymers by burning test

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

Solubility test: Solubility test is also used to identify different synthetic fibres. PA is soluble in 37% Hydrochloric acid in 30 min at room temperature. PA and PES are soluble in sulphuric acid 97-98% in 30 min at room temperature. PE and PP are soluble in Xylene on boiling for 5 min (Inflammable).

Properties

Synthetic netting materials generally are resistant to biodeterioration i.e., they are resistant against destruction by mildew in air and bacteria in water. This is the major advantage of synthetics over natural fibres and it is the prime requisite for a fibre for consideration as a fishing gear material. Besides, synthetic fibres have high breaking strength, better uniformity in characteristics, long service life and low maintenance cost. However, unlike natural fibres, they are prone to degradation under sunlight at a much faster rate. 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.

The relation between inner twist and outer twist is:

$$\text{Inner twist} = \text{outer twist} \times \sqrt{\text{No. of yarns}}$$

The amount of twist decides the softness or hardness of the twine. Based on the amount of twist, the twine is termed as soft, medium, hard and extra hard types. The number of strands in a twine can vary from 2 to 4 but generally 3 strand twines are used for fishing purposes as they possess stability, are free from distortion and round in appearance. The twist can be in two directions, viz., left hand (S twist) or right hand (Z twist). In S twist, the slope of the twisted product follows the direction of the central portion of the letter `S'. Similarly in Z twist, it follows the central portion of `Z'. Generally, the yarns and strands are twisted in the opposite directions for stability. In a double twisted twine, the direction of twist can be SZS or ZSZ for yarn, strand and twine respectively.

Twist coefficient is the measure of twist hardness and is determined by the formula

$$K = (t/m) \times (\sqrt{tex}/1000)$$

where 'K' is the twist coefficient, t/m is the twist per meter and 'tex' is the count in the direct system of numbering.

A coefficient of twist of 110-140, 150-160 and 200 denote degrees of soft, medium and hard twist respectively in PA multifilament netting twine.

Breaking load 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 main factor responsible for weathering is the sunlight, i.e. the ultra violet part of the sun's radiation. Different synthetic fibres show variation in their susceptibility to and rate of deterioration by sunlight depending on the type of polymer and fibre. The rate of deterioration is generally assessed by the loss in breaking strength. The effect of weathering depends on the thickness of yarn as 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.

Choice of material for different gears

Even though different types of synthetic fibres are available, an ideal material satisfying all the requirements of different fishing gears does not exist. The various types of synthetics having different qualities provide a range of choice for selecting the best suited material for each type of gear. The choice of material depends not only on the technical properties but also on the local availability and price. For each type of gear, a particular property of the material may be important; for example, sinking speed for purse seine, transparency and softness for gillnets, high breaking strength and abrasion resistance for bottom trawls etc.

Fishing gears are classified into three main groups based on the strain the net material has to undergo. The classes are: Group 1-Low strain (Fine gillnets); Group 2-Medium strain (Fishing line, traps, scoop nets, dragged nets including small bottom trawls); and Group 3- High strain (Large bottom trawls, gape nets in fast flowing rivers). The material indicated as suitable for each group by Japan Chemical Fibre Association is given in Table 3.

Table 3. Synthetic fibres suitable for different fishing gears

Material	**Groups**	**Fishing Gear**
PA	Group 1,2	Gillnets, purse seines (sardine)
PE	Group 2,3	Trawls
PP	Group 1	Entangling nets
PVC	Group 2	Set nets, Lift nets
PVA	Group 2	Purse seines (Tuna, horse mackerel)

Gillnets: For maximum catching efficiency, the material should be fine, strong, flexible and be invisible in water. The material should be thin and soft but be sufficiently strong to withstand the struggle of the fish to escape. The firmness of fish body and extensibility of the material are also to be considered while choosing the material. The efficiency of gillnets depends on the visibility of nets. These conditions are fulfilled by synthetic fibres especially nylon monofilament yarn. The ratio of diameter of twine to mesh bar is an important criterion to be considered while designing gillnets. Thicker twines are more visible and are easily detectable by the lateral line sense organs of the fish. However, too thin material especially, nylon monofilament, would cut deeply into the body of the fishes and while removing the fishes from the net, the fish gets damaged with cuts and bruises on the body and loss of scales. This results in quality loss and price loss.

Trawl nets: Material should be strong, having good abrasion resistance and cheap to buy. HDPE is the material used in India for trawl nets. In trawl nets, >50% of the drag is contributed by the netting. Hence, use of finer and lighter twines in trawl nets reduce the drag substantially.

Purse seines: Netting material for purse seine should have high specific gravity to increase the sinking speed during setting.The material also should be having sufficient strength for pursing and hauling when huge shoal of fish is caught. Twisted knotless netting and Raschel braided netting are lighter and are widely used for purse seines. But, of late knotted webbing is preferred over knotless webbing, because of the difficulty to repair knotless webbing when damaged. Being a huge net, the material used for purse seine should be thinner (preferably knotless) to reduce the bulkiness of the net. High breaking strength, excellent elastic properties, high specific gravity, low resistance against current, and good water shedding capacity are important properties to be considered while selecting material for purse seines.Mostly, the bunt and selvedge portions are constructed using knotted net for the required strength in these parts of the net. Among synthetic materials polyester and nylon are preferred as they are having high breaking strength. In India, nylon is exclusively used for purse seines and ring seines.

Energy conservation

The modern mechanized fishing operations are highly energy intensive and exploit the limited reserve of the non-renewable fossil fuel. The mechanized and motorized fishing fleet of India has been estimated to consume about 1220 million litres of fuel annually (Boopendranath, 2006). Design of fishing gear and operating conditions influence the drag of fishing gear components. Among different components of gear, netting forms the main component and the hydrodynamic characteristics of netting substantially determine the drag especially in active fishing gears. More than 50% of the total drag of trawl gear is contributed by netting.

For a netting panel, drag depends on the netting area, flow velocity, solidity ratio (ratio of twine diameter to bar length), weaving pattern (braided or twined) and attack angle (angle between the current direction and normal to a net plane). Drag is also affected by knot type, twine material and netting-surface roughness. Knotted netting is more drag resistant than knotless netting. Evaluation of hydrodynamic characteristics of netting panels made of PE netting, PES netting by flume tank experiments by Tang et al. (2019) revealed that the drag generated by knot accounted for 21% of the total drag of PA netting and for braided knotless netting, the drag coefficient of PA netting was about 8.4% lower than that of PE netting and 7% lower than that of PES netting. Compared with twined netting, the braided netting showed a higher resistance to flow (Tang et al., 2019). Therefore, selection of type of material and netting construction are important for energy conservation. Material-based interventions that can largely help in energy saving in fishing are use of (i) knotless netting and (ii) thinner twines with high strength.

The UHMWPE material is an ultimate solution as a material with thin diameter but high strength. The low diameter of these twines and their favourable weight/strength ratio produce up to 40% less drag than conventional fibre structures as the net is pulled through the water or set against tide/currents. Dyneema trawl nets result a fuel saving upto 40%. Due to the lightweight property with minimum drag in the water, the material helps fishers to reduce fuel costs by 40%. New Zealand fishermen reported an average savings of one tonne of fuel per day while using twin-rig trawls made with UHMWPE sold under the trade name Dyneema® (Anon, 2009a). The trawls incorporating Dyneema products showed excellent geometric characteristics and a considerably reduced hydrodynamic drag (Sendlak, 2001). UHMWPE ropes can be used in trawling to substitute wire ropes which helps in weight reduction and drag reduction resulting in fuel saving. In purse seines, the use of UHMWPE facilitates faster sinking due to better filtering and reduced drag. Faster sinking also reduces the chances of escape of the fish shoals encircled.
UHMWPE has made its impact in the fishing and culture sectors elsewhere in the world, its technical and economic feasibility in the Indian context need to be investigated and standardized. Though the material is claimed to have many advantages, the very high cost involved is a major disadvantage. The ICAR-Central Institute of Fisheries Technology has taken up the initiative of testing the performance of UHMWPE netting and ropes in the Indian context in collaboration with DSM, India and Garware Wall Ropes Ltd Pune. The study indicated that UHMWPE trawls are technically feasible as low drag trawls with 17% less drag than conventional HDPE trawls and

saves 10% of fuel (Sayana et al., 2018). The fuel consumption per kilogram of fish captured was also estimated to be 2.9 liters for HDPE trawls and 1.9 liters for UHMWPE trawls with an average (Sayana et al., 2018). UHMWPE rope field tested by CIFT on Dept vessel showed better durability with no greasing or other maintenance. Economic feasibility of the material is under evaluation.

Resource conservation

Bycatch including juveniles, ghost fishing, plastic pollution etc influence the sustainability of resources. Choice of right material and its responsible use can reduce adverse effects on resources and the ecosystem.

Bycatch

Bycatch can be minimized by use of materials which do not absorb water and shrink thereby reduce the mesh size. Nylon netting lose about 10-20% of its dry knot strength on immersion in water while UHMWPE netting do not absorb water. As there is no shrinkage due to wetting, the mesh size and shape are maintained during fishing. Hence, trawls made with UHMWPE fibres especially in the cod end maintain their shape and facilitate better filtering thereby reducing bycatch and juvenile catch. With low elongation, as little as <5%, and no shrinkage in water, the mesh size remains stable during normal use of UHMWPE netting allowing better filtration and reduced bycatch.

Ghost fishing

Ghost fishing is an issue directly dependent on the choice of material. Abandoned, lost or otherwise discarded gear (ALDFG) has always been happening during fishing. But it became an environmental issue since the use of non-biodegradable synthetic fibres. Once gear is lost, it drifts along with the current and waves and as long as the gear configuration is intact, ghost fishing continues. Use of natural fibres such as cotton or jute to rig the floats on the gear ensures disintegration of the float rope within a short period of time. Once, the floats are lost, the gear loses its configuration and sinks to the bottom, preventing further ghost fishing.

One of the reasons for ALDFG to occur is the use of very low-quality material. In India, though BIS standards are laid for minimum requirements to be fulfilled by different netting materials for specific gears, multitudes of low-quality materials are available in the market. Use of low-quality material gives chances of more material to be lost in sea and other waterbodies when entangling with obstructions or in rough weather.

Fishing induced plastic pollution: Since modern fishing gear is made of synthetic fibres coming

under the general term, `plastics’, lost fishing gear/ALDFG adds to the marine/plastic debris. Plastics break down into microplastics (<5 mm in size) which further degrade into nano-sizes at an extremely low degradation rate taking several hundreds of years. Microplastics in seawater and marine sediments are rapidly increasing, and are entering into the food chain becoming a long-term threat to the mankind. It is estimated that ALDFG contributes 10% of the marine debris and hence, fishing gear must be operated cautiously to avoid gear loss either accidentally or deliberately.

Biodegradable netting: Use of biodegradable float line, prevents ghost fishing, but the gear sunk on the sea bottom adds to plastic debris and entangle with coral and other bottom biota. Bioplastic materials which are biodegradable are more beneficial to prevent ghost fishing. In the last couple of decades, more attention has been given to bioplastics and its application in fishing industry. Plastics derived from renewable sources such as polysaccharides: cellulose, starch, chitin and others or from protein sources such as silk, collagen, soy, casein which are abundant in nature are collectively termed as bioplastics. Synthetic bio-based fibres are produced by modification of natural polymers, synthesizing by microbial systems and synthesizing polymers from bio-based monomers. All biobased plastics are not biodegradable as biodegradability of the plastics depends on the chemical structure and not on the source. Petroleum-based polymers such as PBAT (polybutyrate adipate terephthalate) and PCL (polycaprolactone) are biodegradable.

Polylactic acid or polylactide (PLA) is one of the most widely used bioplastics. PLA (is based on lactic acid, a natural acid, which is mainly produced by fermentation of sugar or starch with the help of microorganisms. Blending PLA with other polymers improves its mechanical properties.

In the fishing industry, environment friendly fishing line made of biodegradable polymer made from poly butylene succinate (PBS) is a recent development.`Bioline'is a commercial fibre made from PBS which retains its strength and durability for few months of use and then completely degrades in water (salt or fresh water) through the enzymatic reactions of naturally occurring microorganisms in the water. It does not deteriorate when kept clean and dry, but when exposed to bacterial activity underwater or underground, it deteriorates viz., it retains its strength and durability for the first 10-12 months of use and then completely degrade in water or on land within five years. FIELDMATE™ is another example for biodegradable polymer. If exposed for three months in salt or fresh water, it decomposes through the enzymatic reactions of naturally occurring microorganisms, before eventually being reduced to water and carbon dioxide.

Conclusion

Plastic materials due to very good strength, durability and other vital properties, are extensively used in fisheries. The introduction of synthetic fibres has revolutionized the fishing industry and it can be considered as the major single factor which led to the development of today's efficient fishing gears. However, the responsible use and disposal of materials are very essential for resource conservation, energy saving and ecological well-being.

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