PERFORMANCE EVALUATION OF COMMERCIALLY IMPORTANT INDIAN AND IMPORTED FISHING HOOKS

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CERTIFICATE

This is to certify that this doctoral thesis entitled **"Performance Evaluation of Commercially Important Indian and Imported Fishing Hooks"** is a bonafide record of research work done by **Mr. Gipson Edappazham, M.Sc.,** under my guidance and supervision in the Fishing Technology Division of Central Institute of Fisheries Technology, Cochin, in partial fulfilment of the requirements for the degree of **Doctor of Philosophy** in Industrial Fisheries under the Faculty of Marine Sciences of the Cochin University of Science and Technology. I also certify that no part thereof has previously formed the basis for the award of any degree, diploma, associateship, fellowship or any other similar title of any University or Institution.

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DECLARATION

I, **Gipson Edappazham**, hereby declare that this doctoral thesis entitled **"Performance Evaluation of Commercially Important Indian and Imported Fishing Hooks"** is the record of the original research work carried out by me under the supervision and guidance of **Dr. Saly N. Thomas**, Senior Scientist, Fishing Technology Division, Central Institute of Fisheries Technology, Cochin, in partial fulfilment of the requirements for the Ph.D. degree in Industrial Fisheries under the Faculty of Marine Sciences of the Cochin University of Science and Technology and that no part thereof has previously formed the basis for the award of any degree, diploma, associateship, fellowship or any other similar title of any University or Institution.

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(Gipson Edappazham)

Dedicated to my family, friends and all our fishermen……..

CONTENTS

Chapter - 1

INTRODUCTION

Hook is a simple, easy to operate and selective fishing device. They are counted among the most ancient devices used for fishing (Manoharadoss, 2002; Anon, 2004b). This fishing method has been in existence from the pre-historic times and has survived centuries to attain the current status. It is evident from the excavation of a unique late bronze age copper fish-hook from Bet Dwarka Island, Gujarat, west coast of India that advanced hook fishing technology existed in ancient India also (Gaur and Sundaresh, 2004). Hook forms the indispensable part of any hook and line fishing system. Hook and line fishing is a highly selective, economically viable low energy fishing method well suited for the exploitation of sparingly distributed fishes (Løkkeborg and Bjordal, 1992). The principle of hook and line fishing is to offer partly fixed bait to the fish which then finds itself unable to release the bait so that the fish can be lifted from the water together with the bait (Brandt, 1984). The hook serves the functions of holding the bait, enticing the fish to it and ensuring that the fish shall be unable to spit it out with the bait after swallowing it. It usually penetrates into the mouth of the fish when the bait is taken or when the line is pulled.

The hook and line fishing can be used where other gears can not normally be operated like rocky and uneven bottom grounds, shallow and very deep waters etc. Mathai (2002) has reported that about 12% of all fish catches in the world was made by hooks and lines. It is estimated that 90% of the targeted fish biomass has been removed from large areas of the oceans in just 50 years of industrial fishing (Myers and Worm, 2003). Keeping this in mind, the International Code of Conduct for Responsible Fishing developed by the Food and Agriculture Organization (FAO) in consultation with member countries of the United Nations (UN) points to the need for concentrating more on the artisanal and small-scale fishing methods, which use selective and energy efficient fishing gears such as hook and line for the sustainable exploitation of aquatic resources, protection of aquatic environment and energy conservation (FAO, 1995).

1.1. Hook and line fishing in India

1.1.1. Marine sector

Hook and line fishing is becoming increasingly important in the Indian fisheries as the tunas are in great demand throughout the world market due to their excellent meat quality and it is a well established fact that India has a great potential for further development in tuna fishing. The long lining system has been identified as the most efficient and cost effective system for harvesting oceanic tuna resources. Long lining consumes only 0.15 to 0.25 kg of fuel to catch one kilogram of fish in contrast to 0.8 kg required by trawling (Gulbrandson, 1986). More than 95% of the world's tuna and tuna like fish harvested commercially are caught using either pole and line or purse-seining or long lining (Vijayan, 2002). In recent years the growth rate of marine capture fisheries sector is showing a declining trend as most of the capture fisheries worldwide have apparently reached their maximum potential production except in some fisheries like tuna fisheries in Indian Exclusive Economic Zone (EEZ). The coastal zone up to 50 m depth of the Indian EEZ is intensely exploited while the region beyond 50 m depth with high potential of oceanic resources like tuna and tuna like fishes are hardly exploited (James, 2005).

In 2004, the total landing of tunnies amount to 45,684 tonnes (CMFRI, 2005). The annual potential yield of tuna and tuna like fishes along the territorial/coastal waters of India is estimated to be 2.8 lakh tonnes of which only about 23% are harvested (James, 2005). This leaves a wide gap for further improvement. Apart from this, the tuna resources in the oceanic waters of Indian EEZ is estimated to be about 2 lakh tonnes which remains almost unexploited due to inadequacies in suitable craft and gear, technical skill, fishing regulations etc. (Vijayan, 2002). While distant water fishing fleets of foreign countries intrude into Indian waters and harvest enormous quantity of tunas, it is highly essential for India to formulate and implement programmes for successful harvesting and utilization of her rich tuna resources. In the context of escalating fuel prices, hook and line fishing has gained much more importance, as it is a low energy fishing technique suitable for the exploitation of deep-sea resources. It has got a promising future in India for the harvesting of under exploited tuna resources in the Indian EEZ. It is practiced by both artisanal and mechanized sectors. It is estimated that a total of 3,94,000 fleets operate from South east and North west regions of Indian coastal line for hook and line operations, which contributed about 32,000 tonnes of fish in the year 2003 (Annam *et al.*, 2004). It is expected that hook and line fisheries sector will grow on phenomenal rate in the years to come. Since huge capital investment is required for new long lining vessels, conversion of existing trawlers for long lining is considered to be pragmatic alternative for addressing this issue. As these converted vessels could be used for trawling in the lean seasons when the tunas are not available, fishing can be conducted round the year.

1.1.2. Inland sector

Apart from the marine resources, the inland resources of ndia offer immense scope and potential for developing the capture fisheries, and hook and line fisheries have an important role to play (Jhingran, 1989a, 1989b). Indigenous and introduced fish varieties like mahseers, catfishes (*Aorichthys seenghala, A. aor, Wallago attu, Silonia silondia, Pangasius pangasisu*), murrels (*Channa striatus and C. marulius*) and the trouts (*Salmo trutta fario, Salmo gairdneri*) form the potential inland hook fishery group in India. This rich availability of favoured species coupled with diverse inland water bodies suitable for hook and line operations offers sustainable development of this sector.

1.1.2.1. Sport fishing / Recreational angling

Sport fishing or "Angling' started with the invention of angled fish-hook (Tripathi, 2006). Experts opine that the word 'angling' has been derived from Greek 'ankos glen' (meaning barbed hook) or the Old English 'anga hook' (angled hook). Angling is an interesting sport that provides entertainment, nutritious food and foreign exchange. It can also help in the development of several ancillary industries related to tourism.

On the recent advent of large-scale tourism in India especially in states like Kerala, Goa, Himachal Pradesh, Jammu and Kashmir etc. has opened up recreational fishing activities, the main thrust of which is on angling. India has got a tremendous potential in recreational fisheries, especially in the state of Kerala as a result of the fast growing tourism industry (Korakandy, 2000). He has pointed out the long tradition of recreational fishing in India even before independence. But this sector was neglected after the independence. There is a renewal of interest in recreational fishing and the tourism development in the country is expected to give it a further push. Recreational angling (sport fishing) using hook and rod/pole is also gaining importance in India especially in the states of Himachal Pradesh, Arunachal Pradesh, Assam, Kerala etc. (Korakandy, 2000). The type and sizes of hooks have an important role to play here as different regions and targeted species require different hook designs. It is also important that the recreational fishing needs to be introduced on a responsible manner. For instance, in 'catch and release' type of recreational fishing, the captured fishes are released subsequently. Appropriate hook types have to be used to ensure minimum mortality and to conserve fish stocks for continued fishing activities.

The hook and line fishing generally referred to as a single man handline has now evolved to automated large-scale longline systems. Though the basic design of hook has not changed over the time, the material, shape and manufacturing processes have changed. New materials and manufacturing techniques have resulted in different styles of high quality hooks for target fishing. It is important to know the history and evolution of hooks for further studies on this unique fishing gear.

1.2. History and evolution of hooks

From the pre-historic ages, man tried out quite a number of ways of catching fish and hook and line is one method that has survived the centuries. Many present day hook patterns are results of "trial and error" from the Stone Age. Why a particular hook has been designed with a particular gape, bend, shank, barb and eye is the result of experience gained from the collective efforts of hundreds of generations of fishermen. The history of hooks is believed to have passed through the transition phases: from wood, shell and bone of Stone Age to copper, bronze, iron and steel. The present day hooks are well-tempered durable metal hooks mostly of alloys which are specially protected by galvanizing, tinning, bronzing, enamelling etc. to prevent corrosion. The metal hooks must have sufficient hardness striking a balance between strength and flexibility and be resistant to water.

Herd (2003) reported that the fishing hooks had evolved from the Gorges, a device used by many primitive cultures, which is frequently found in prehistoric sites. However Brandt (1984) opined that the modern angling hook has not been developed from gorges even though gorge was certainly older than the curved hook. Gorges were small straight or little bent sticks, made of wood, bone, flint or turtle-shell pointed at either end, tied at the middle or attached to a line knotted through a hole in the centre of the gorge and inserted lengthwise into a bait while fish swallows the gorge along with the bait, by the pull of the line, the gorge takes up a transverse position across the fish’s throat. Gorges with one pointed end and a line fastened at the other end also were in use. Even though gorges are hard to conceal, difficult to bait, hard to hook large fish on, and liable to lose its hold while the fish is being hauled, are still used in some places.

1.2.1. Pre-historical hooks

There are no reliable evidences indicating the exact period from which various kinds of fishhooks have been in use, but it is quite probable that the Cro-Magnon Man, who appeared 30 - 40,000 years ago, was familiar with fish hooks and used it in his struggle for survival. The problem faced by archaeologists who are trying to establish the historical facts about fishhooks is that the materials used were not very durable and it is believed that the very first types of fishhooks were made of wood. Neolithic man used hooks made out of bone, shell, or thorn depending on the materials that were easily available to them (Anon, 2004b).

1.2.2. Copper and Bronze hooks

Available records show that copper hooks were made in Bauchen, 7000 years ago (Anon, 2005a). The copper was then gradually replaced by bronze owing to its superior tensile properties. Old civilizations along the banks of the Euphrates and the Tigris rivers were reported to have utilized copper for making fishing hooks. Many records are available of copper hooks found from this area that are half a thousand years older than Abraham's Mesopotamia (around 1,800 BC) (Helsinki, 1970). Numerous findings of bronze hooks were also reported from Crete and Italy. Helsinki (1970) has also described about very intricately designed hooks that have been excavated from Pompeii and Herculaneum. It is indicative of the fine craftsmanship that was available during that era. Gaur and Sundaresh (2004) have reported about a unique late-Bronze Age copper fishhook excavated from Bet Dwarka Island, Gujarat, west coast of India.

1.2.3. Steel hooks

The tools discovered from some burial mounds indicate that even before the Vikings (8^{th} to the 11^{th} centuries), professional blacksmiths used to make fine fishing hooks made out of wrought iron, which is still in practice in some remote areas (Anon, 2004b). But good quality steel was scarce during that period as all iron cannot be tempered into steel. No reliable records are available on the introduction of fishing hooks made out of good quality steel. According to British angling literature, there were excellent professional hook makers around 1600 AD (Anon, 2004b). On the advent of industrialization, the professional blacksmiths who were making hooks at their houses started small-scale industries, which have now evolved into multinational hook manufacturing companies equipped with sophisticated machines and quality control systems.

1.2.4. Typical fishing hook

The hook serves the functions of holding the bait, enticing the fish to it and ensuring that the fish shall be unable to spit it out with the bait after swallowing it. It usually penetrates into the mouth of the fish when the bait is taken or when the line is pulled. Understanding the basic parts or components of a fishing hook will make it easier to find the right hook for a particular fishery.

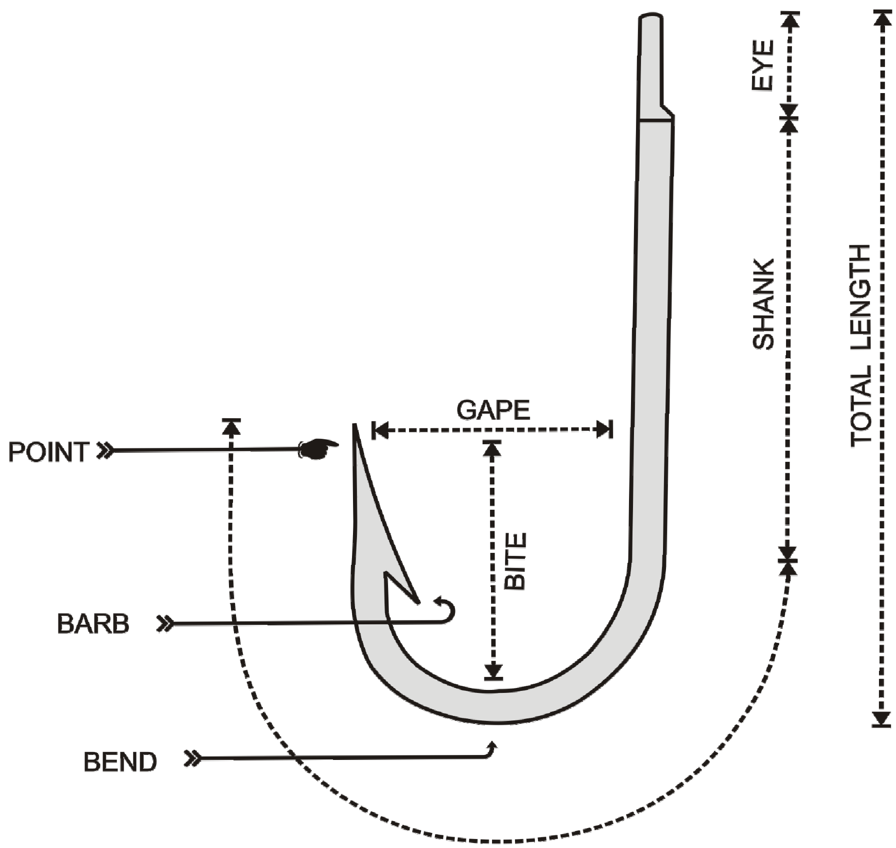

Fig. 1.1. Parts of a typical fishing hook.

Fig. 1.1. depicts the various parts of the hook with their proper names: eye, shank, bend, gape, bite, point and barb. Eye is the portion, where the line is attached to the hook. It comes in a variety of forms like: ringed, looped, tapered, looped tapered, flattened, open, swivel type and needle type. The shank is the leg of a hook, which extends from the bend up to

the eye, and could be short, regular or long depending upon the hook's design and usage. Short shanks are generally used when fishing with natural baits. Long shank hooks are essential for sharp-toothed fish, and also for fish that suck in their food. The longer shank allows easy removal of hooked fish. Hook shanks are manufactured in many different shapes. The most commonly used are straight shank, curved shank and barbed shank. In straight shank, the hook shank is straight from eye to bend. Shanks are often curved or barbed for specific reasons, e.g. to accommodate a special fly imitation, or to anchor baits, such as worms and soft baits.

Bend is the main distinguishing characteristic of a fishing hook. The gape is one of the most important dimensions of a hook and is the shortest distance between point and shank. It is also termed as 'gap' by manufacturers in some non-English speaking countries (Anon, 2002). It has been accepted that there is a relatively standard relationship between gape and hook size but a review of the actual measurements revealed this as not true (Anon, 2002). Bite/throat is termed as the distance from the apex of the bend to its intersection with the gape. If this distance is too short there is a greater chance of fish escaping from the hook. The final part of the hook, the point, is the tip of the hook that penetrates the body of the fish. It occurs in straight, reversed or even curved. There are many types of points to choose from like spear, needle, knife-edge, hollow, rolled-in and diamond/triangular. In some hooks a back ward pointing sharp barb is provided at the point that prevents the escape of fish, once it is hooked. The barb also helps in holding the bait. Usually one barb is provided pointing to the inner side of the hook while hooks with one to three barbs pointing to the outside are also seen. The spear represents that portion of the hook measured from the bottom of the bent forward to the tip of the point. The term ‘heel’ is used to refer the portion of the bend, which is affected by the forging process.

1.2.5. Manufacturing process

Modern day fishing hooks are manufactured from high carbon steel wire. Some times, steel alloys are also used. Hooks are basically manufactured by two ways, using wire and by forging (Anon, 2002). In hooks manufactured by bending metal wires, the shank will be circular in cross section, whereas in hooks made by the forging process the shank will be oval in cross section. A wire of a proper diameter is selected and is cut to the exact predetermined length that will be required for a finished hook of a particular size and style. The "point" is made by hand-filing the wire or using a grinding machine or else by diagonally cutting the wire. If a tapered eye is needed in the hook, the forward end of the wire is ground to the appropriate taper. In the next step, the hook’s barb is created by cutting into the wire at an acute angle and raising a small sliver of metal resulting in a barb. It is followed by shaping or forming a bend by physically bending the wire to the desired shape and style. For this dies are used which exactly match the inside radius of the desired hook shape like round bend or Kirby or Limerick bend.

Generally, forging is a term applied to a process of forming metal implements using moulds. In hook manufacturing, it refers to the flattening of the round wire laterally to increase its strength in one plane or direction. The forging process can enhance the strength of the wire up to 20% (Anon, 2001). Commonly, hooks are forged on both sides beginning at a point behind the barb, and extending throughout the bend up to the hook shank. Often the forging will include much of the hook shank. It is effected by placing individual hooks into a press, which flattens the round wire to a controlled thickness. The next stage involves the creation of the "eye" according to the hook style. Wire hooks are cheaper to manufacture but are weak and bend easily. Forged hooks are stronger, heavier and expensive. They break rather than bend and have sharp points.

In modern hook manufacturing process, the formed hooks are immersed into an acid bath, which dissolves any minute burrs or abrasions, which might have occurred during manufacture. It results in a cleaner metal surface and thus, sharper hooks. This process generally called chemical sharpening is followed by many of the modern hook producers. Manufactures like Mustad, Tiemco and Daiichi refer this process as chemically sharpened, whereas Eagle Claw terms it as Laser Sharpening and Partridge calls it Flashpointing (Anon, 2002). Manual sharpening using a stone or file cause rusting unless stainless steel bars are used. Rusting can be minimised by using cadmium plated or tinned hooks.

The most important step in hook manufacture is the tempering of the hook in which the metal is hardened to improve strength. Hooks are heated to specified temperatures by placing in an oven and then they are immersed in a liquid coolant, which brings about a rapid decrease in temperature. This process hardens the metal and substantially increases its resistance to unbending resulting in hooks, which are very strong but not brittle. The tempering has to be perfect other wise there is a chance of the hooks becoming brittle due to over processing or too soft due to under processing. Achieving a balance between strength and flexibility is very difficult. The formulation of the coolant and technique of tempering is specific for each manufacturer, which is kept as a trade secret. Some manufacturers use electronic tempering process, which enables tempering to be done in a stable condition. After tempering, the hook is cleaned; generally by the tumbling process whereby the hooks are cleaned with an abrasive. The last stage in the hook manufacture is the application of desired finish or protective coating to it. This is accomplished by lacquering or electroplating. The common finishes applied to the fishing hooks are: tinned, nickeled, ‘blued’, ‘Japanned black’, ‘red’ and ‘bronzed’. In ‘blued’, ‘Japanned black’, red and ‘bronzed’ fishing hooks, the surface finish is given by coating it with alkyd resin based coloured coatings. Different methods for formation of Zn–Ni alloy-based metallic coating include electro deposition, PVD (Physical Vapour Deposition) coating and addition of Zn–Ni master alloy in hot-dip galvanizing bath. The Zn–Ni alloy coatings are superior to pure zinc coating as the former has high corrosion resistance and good weldability. Moreover, nickel can be considered as a viable substitute for cadmium in marine environments. Incorporation of nickel in the galvanized coating makes the alloy layer more compact. The nickel-enriched barrier layer formed during the course of hot-dip galvanization process can effectively prevent penetration of aggressive ions like Cl^- and ClO_4^- in high chloride environments. The finished hooks are then inspected for any defects, packed and marketed.

1.2.6. Classification of hooks

Fish hooks come in several shapes and sizes. Basically hooks are classified into wire and forged depending on the manufacturing. They can also be broadly classified into barbed hooks and barb less hooks. Apart from this, fishing hooks are variously classified in terms of their shape, point, number of bends, gape, eye, mode of use, targeted species, make/brand etc (Fig. 1.2.).

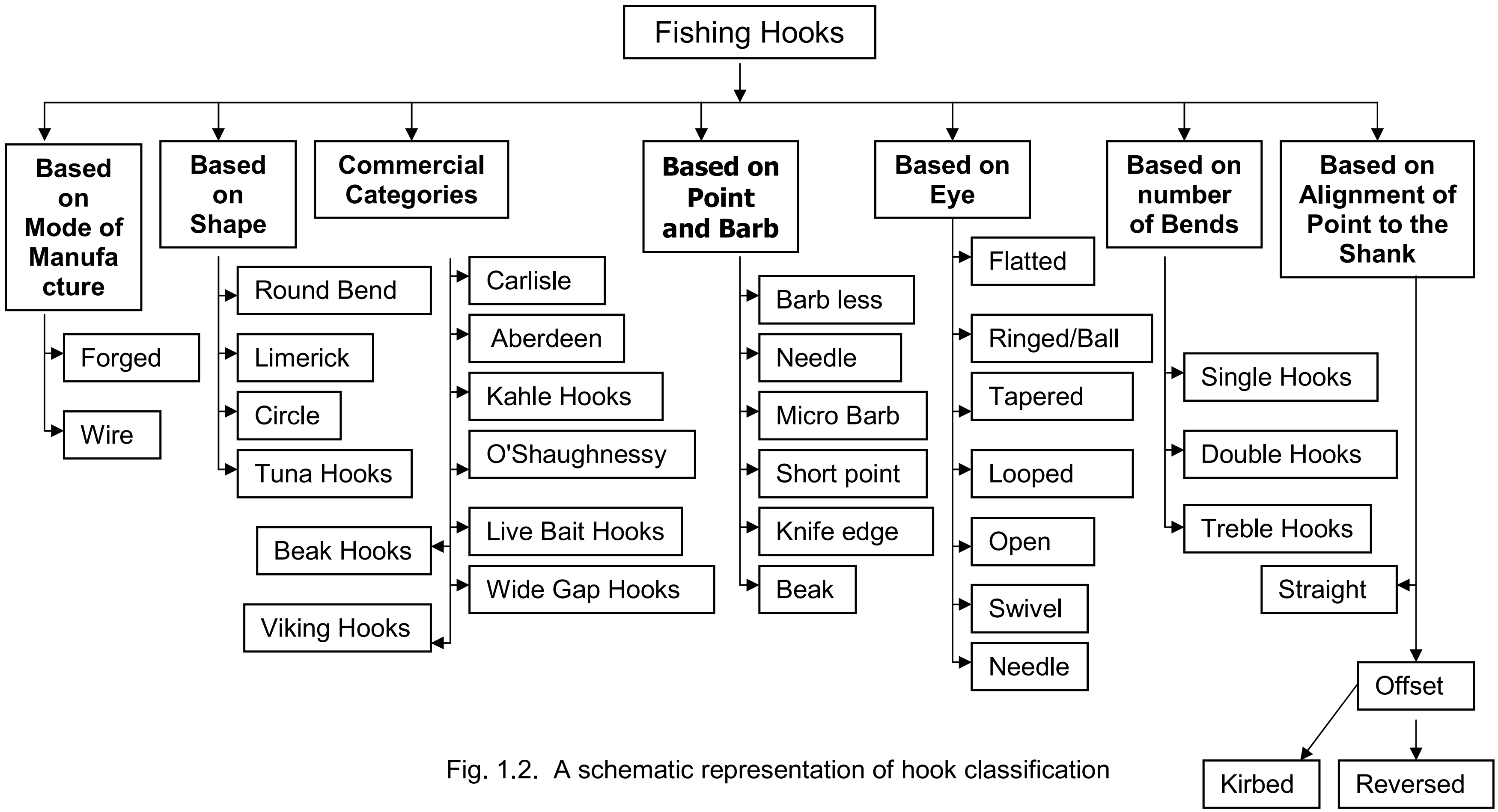

Fig. 1.2. A schematic representation of hook classification

1.2.6.1. Commercial categories of fishing hooks

There is no standard classification used at commercial level. They are commercially identified based on their popular name or a particular character. The most common commercial categories of hooks are given below (Fg. 1.3.):

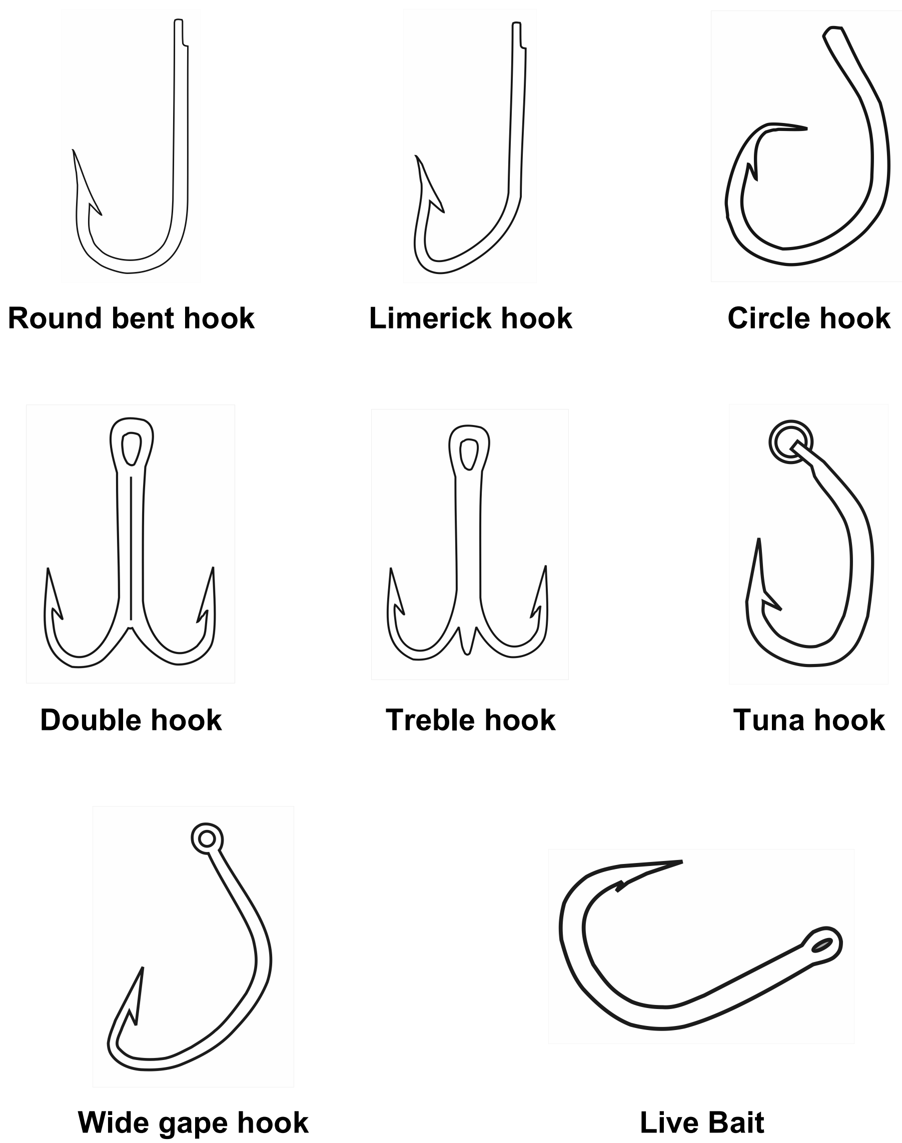

Fig. 1.3. Important commercial categories of hooks

Round bend hooks are the common range of hooks with a perfect round bend, used both in fresh water fishing and in marine waters and are usually barbed. They are also known as “J” shaped hooks. Limerick hooks have characteristic sharp angle in front of the bend used for tying flies. ‘Crystal hook’ is a limerick bend hook in its most extreme way, with a very sharp front angle bend.

Circle hooks have a circular shape with a point that turns inward to the shank at about 90^o angle. Atlantic States Marine Fisheries Commission has defined circle hook as a non-offset hook with the point turned perpendicularly back to the shank (Anon, 2003). These hooks, reported even in the prehistoric cultures (Montrey, 2004) have been in use in the commercial longline industry since 1960s (Moore, 2001; Prince *et al.,* 2002). Modern recreational anglers started using these hooks from 1980s only. Circle hooks promote healthy catch and show good size selectivity, minimizing the number of undersized fish hooked. It is found that they have high catch rate and are easy to use (Brooks, 2004a). Circle hooks come in a light wire and a heavy-duty variety and depending on the size and type of fish to be caught, the suitable hook is selected. Brooks (2004a & b) shared his experience with 5/0 and 6/0 circle hooks and stressed its importance, both as a conservation tool and as a tool to increase the hookup to catch ratio. Even when the fish swallows the Circle hook with bait, the hook comes out of the throat without penetrating. As the fish swims away, the hook is pulled to the corner of the mouth where it penetrates into the body. The effectiveness of circle hook depends on the hook size, fishing style, feeding mode and mouth morphology of the fish. Circle hooks minimize the incidence of turtles being hooked and are evolving as a turtle friendly fishing gear (Anon, 2005a).

O'Shaughnessy hook is a standard hook, relatively thick, forged with a very strong bend and not likely to bend out of shape. Sizes range from #3 to as large as 19/0. They are recognized as outstanding for sea angling and heavy freshwater angling. Aberdeen hooks are mostly used in freshwater, in smaller sizes and are also used in saltwater. They are generally made from shaped wire with a perfect round bend applied on a long shank. It can be bent back into shape several times before it becomes too weak. However, once a fish is hooked and the barb has completely penetrated, this hook holds quite well. These hooks are modified with bends in their shanks for use in jig molds. Live bait hooks generally have a shorter shank than other hooks. Whether that is to allow the live bait to swim more freely or to be less apparent to the fish is debatable. These hooks come in regular and circle designs. Regular live bait hooks will be swallowed and result in gut hooks most of the time. Circle live bait hooks provide a greater chance for a good release of the hooked fish onboard – a desirable property in live bait operations. Kahle hooks are also used along with live baits. The curve on these hooks makes them ideal for live bait. Made from the same wire as the Aberdeen hooks, they will bend if hung on the bottom of some structure. However, once a fish is hooked, the design of the hook prevents it from being straightened. Wide gape hooks are made by bending the wire resulting in a wide gape. These hooks are suitable for baiting with shrimp.

Tuna hooks have a special shape and are used exclusively for tuna fishing. They usually have a ringed eye, short and thick shank with a turned down eye and barbed point. The tuna hook design is believed to be perfected by the Japanese. Viking hooks composed of a wide range of hooks used mainly as fly hooks. Their ‘turned up’ eyes facilitate easy fly tying. A double hook has got two bends, usually on a common shank. They are mainly used in trolling. Similarly, treble hooks consist of three separate hooks forged at the top to make one eye. The design helps to have better holding and hooking power than a single hook. Rotating trebles with points and bends in the hook facing different angles help in easy penetration and holding. These hooks are widely used in trolling using artificial baits for catching active predator fishes like seer fish, sail fish etc. They are used with dough bait also.

1.2.6.2. Based on point and barb

Based on the characteristic of point and barb, the hooks are classified into the following groups (Fig. 1.4.):

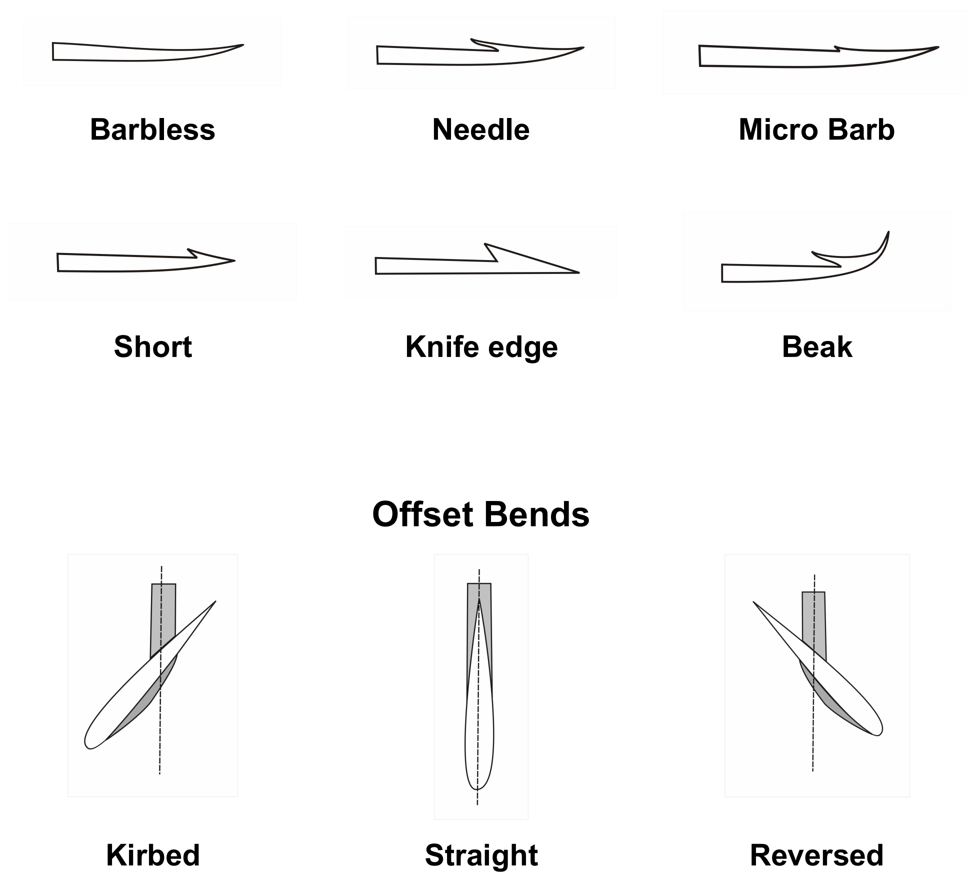

Fig. 1.4. Classification of hooks based on point and barb

Barb less hooks are devoid of any barbs on the point. These hooks are widely used in tuna fishing along with live baits. The absence of the barb helps in easy release of the fish and much less handling of the fish. This helps in better survival rate of fish in recreational fishery. The needle point ground on all sides has the best penetrating ability but is easily blunted. Micro barb hooks used mainly in fly-fishing come with just a tiny barb, which helps to hook the fish with minimum injuries and better survival rate after release. The point is very short in the case of short point hooks. In knife edge hooks, point is made into a sharp edge resembling that of knives for better penetration of the hook. In beak type of point, the point is given a bend resembling the beak of a bird. This characteristic bent in point is found suitable on a great variety of hooks, especially hooks for bait fishing. The point position ensures more efficient hooking of soft-mouthed species.

Hooks are also classified according to the alignment of the point with regards to the shank (offset). They are kirbed, reversed and straight. Kirbed bend hooks are the world's most popular range of hooks. Available in many different patterns of which all are "Kirbed" a term used for the point bent towards the right of the shank. The very name owes to the legendary hook maker Mr. Charles Kirby in Harp Alley, Shoe Lane, 'the most exact and best Hook-maker' of his time, from whom we can trace the development up to our own time (Mustad Kirby Sea Hooks). In reversed bend hooks, the point bent towards the left of the shank whereas in straight hooks, the point remains straight to the shank.

1.2.6.3. Based on eye

Based on the design of the eye, the hooks are classified in to the following groups (Fig. 1.5.).

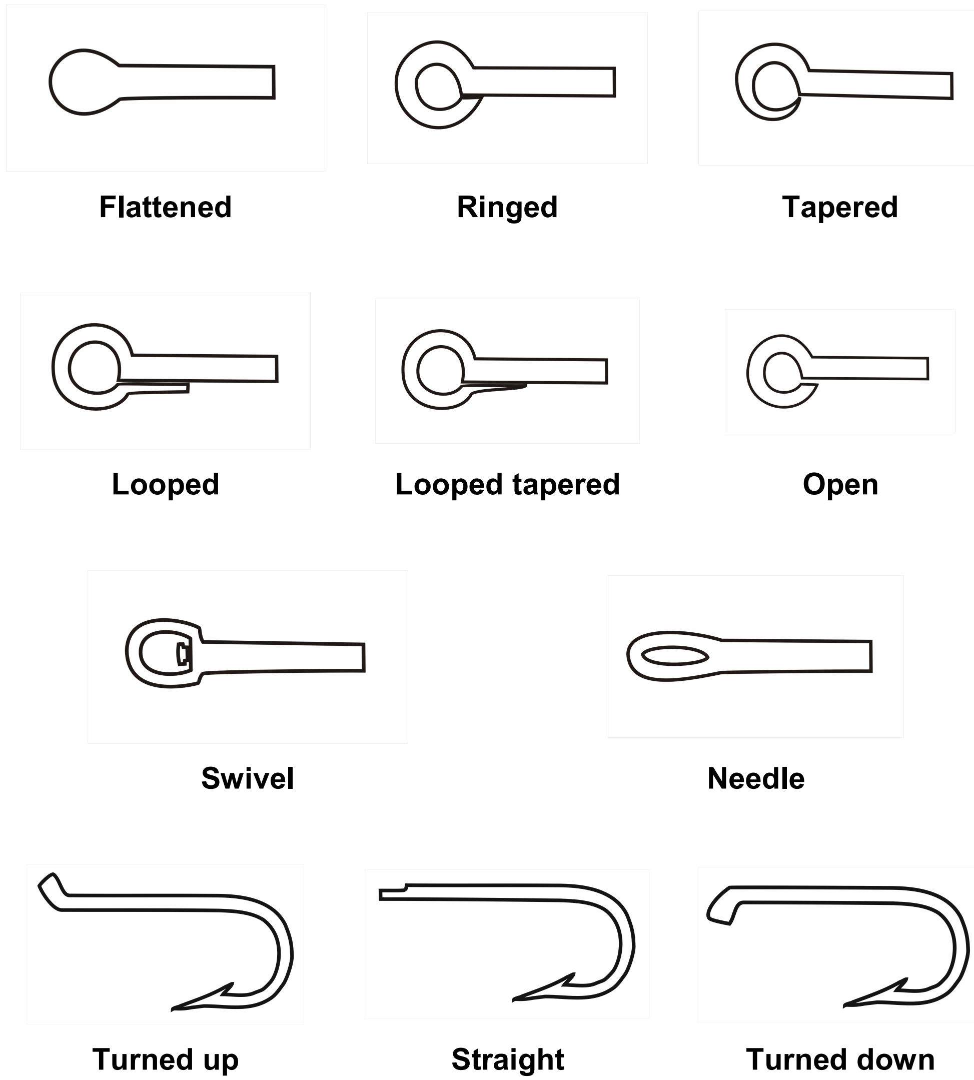

Fig. 1.5. Classification of hooks based on eye and the angle the eye makes with the shank

Apart from these types, some times the hooks are classified according to the angle the eye makes with the shank as given in Fig. 1.5. Here the bend of the hook wire is made near the eye where the eye is to be `turned up', `turned down' or 'straight.

1.2.7. Hook numbering and size of hooks

There is no uniform, universally accepted system of hook numbering in practice for designating different hooks. Hook sizes are mostly arrived at by different proprietary standards between different manufacturers. The gape, shank length etc. of standard hook sizes of different companies often differ. Visual familiarity with various hook patterns is the only workable gauge for the fisherman as there is no uniform standard for hooks on which he can rely.

Andreev (1963) described three types of numbering systems used to denote the size of fishing hooks. These are Marine numbering, River numbering and the third based on the gape size of hooks. These systems are interrelated and also related with the weight of the hooks. According to him, the physical parameters of the hook were independent of the shape and nature of the hook.

Baranov (1977) explained about two numbering systems in practice for hooks viz., Sea numbering system and River numbering system. In his paper he also describes about a system in which the size of a hook is expressed in terms of weight (kg) of 1000 hooks.

A comparison of different hook numbering systems is given in Table 1.1.

Table: 1.1. Comparison of Hook Numbering Systems

Hook numbers			
Marine Numbering	**River Numbering**	**Width of Bend (mm)**	**Weight of 1000 items (kg)**
1	10/0	36	11
2	9/0	31	8
3	8/0	27	6
4	7/0	23	4
5	6/0	20	2.7
6	5/0	18	1.8
7	4/0	16	1.3
8	3/0	14.5	0.9
9	2/0	13	0.65
10	1/0	12	0.46
11	1	11	0.34
12	2	10	0.25
13	3	9	0.19
14	4	8	0.12

Although attempts have been made to set a standard by measuring the hook in fractions of an inch, the system has never been successful because it merely represents the length of the shank. A hook is really two-dimensional since the gape can vary greatly from one pattern to the next. In general, the commercial measures go from the smallest size 32 (which is barely large enough to hold between two fingers) and count down. As the number decreases, the size increases all the way down to a number 1 hook. At this point the number changes to a designation of “aughts” or zeroes. A 1/0 (pronounced “one aught”) hook is the next larger size to a number 1. A 2/0 is larger still, and this numbering scheme goes as high as 20/0 (River Numbering). The full size breakdown from smallest to largest looks like this:

(Smallest) 32, 30, 29, 28, 26, …………….. 4, 3, 2, 1, 1/0, 2/0, 3/0, 4/0, ………. …………17/0, 18/0, 19/0 and 20/0 (Largest)

All of these hooks come in short, regular, or long shank versions. The most popular brand Mustad hooks range in size from 19/0 down to 32. Size 19/0 is the largest shark hook; size 32 is the smallest fly hook. In Indian Standard IS: 9860 (Part I) - 1981, a comprehensive specification for seven different types of barbed fishing hook viz., Single straight flat hooks, Single straight ringed hooks, Single kirbed flat hooks, Single kirbed ringed hooks, Double round hooks, Treble hooks and Single kirbed turned down ringed hooks is given. A method to designate hooks by its type, size as gape width, wire diameter, length and number of this Indian Standard is also given. For example: a fishing hook of single kirbed flat type of size 8.5, wire diameter 0.8 mm and length 18 mm shall be designated as: *Fishing hook, single kirbed flat, 8.5, 0.8, 18, IS: 9860 (Part I)*. However, the hook sizes specified in this system is not at all followed in the industry.

1.2.8. Selection of proper hook

Selection of the right type and size of hook is very critical for successful hook and line fishing operations. A good understanding of different hook pattern, their usage and the numbering system is important for selection of hook for a particular fish. Choice of hook depends on several factors such as the quality of the hook, the size of the targeted fish, its preferred bait, feeding habit, the fishing area (marine/inland) and the size of the line used. The mechanical properties of the hook and the biological aspects of the target fish affect catching process (Lokkeborg and Bjordal, 1992). A large hook is less readily broken or straightened and its wider gap may allow the hook point to engage more deeply in the mouth cavity. Larger hooks require a stronger force to allow the hook to fully penetrate the inside of the mouth cavity (Johannessen, 1983). Hence large hook may be effective in preventing escape of hooked fish especially larger fish. Generally, fishermen select smaller hooks for smaller fish and bigger hooks for bigger fish based on their experience and acquired knowledge. Here the physical and behavioral characteristics of the targeted fish play an important role. The line size, the type of fish and the type and size of hook are to be matched and should be selected as a package.

The mouth of the targeted fish, its size, shape, structure and fighting pattern also influence the choice of hook. In the case of baited hooks, the hook needs to be large enough to be able to hold the bait and hook the fish, yet it should be sufficiently small enough that it does not hide the bait. A hook with barbs on the hook shank is found to be good for live bait and an offset worm hook for artificial bait. The live bait hook should be large enough that it does get the attention of the targeted fish when it is in water along with the live baits and small enough that it does not kill the bait. The hook should be sharp as dull hooks lead to escape of fish as well as unwanted mortality. The size of the hook and the gape should be proportional to the size of the bait. According to Baranov (1977) the success of the catch from a hook depends on the angle, the spear of hook makes with the direction of the pull. The more acute the angle, the more is the chance of the spear easily penetrating the fish. Treble hooks are used along with dough bait and artificial baits. The cost of the hook also is important. Mechanically sharpened hooks are easy to re-sharpen, which will save money but can cause rusting unless stainless steel barbs are used. Chemically sharpened single-use hooks are sharper, but more expensive.

There are a lot of indigenous and imported brands and models available in the market. This makes the selection of the right hook more difficult. The important brands of fishing hook available in India include Mustad (Norway), VMC (France), Youvella (Korea), Maruto Eagle Wave (Japan), Addya (India), Viaadi (India), Fish (India), Pasupati (India) etc. Besides, there are different centers along the coastal belt of the country where local black smiths make hooks. A comparative study of the hooking efficiencies and the response/behaviour of the fishes towards these hooks would help the fishermen in selecting the right hook.

1.3. Background and scope of the study

Hooks of different shape, size and make are used in fishing gears like long lines, drop lines, troll lines and hand lines. As early as in 1976 it was reported that more than 30,000 different kinds of fishing hooks are being produced on an industrial scale (Baranov, 1976). A large variety of indigenous and imported, branded and unbranded hooks made of different materials are available in the market. A widely accepted brand of hooks in India is the Mustad brand. Of late, fishing hooks and lines, of varying quality and price manufactured under different brands in India and abroad are available in the market.

As newer materials and technologies are being used in the manufacture of fishing hooks, there is great need for systematic studies on their properties and performance. Earlier studies on fishing hooks, have lost their relevance due to the arrival of new technologies and materials. Many of these hooks do not have any reference or standards with regard to their physical and mechanical properties, chemical properties, resistance to corrosion etc. The quality and performance of these hooks are quite varied from one type to other. Different manufacturers classify or number their hooks differently. This makes selection of the right hook very difficult.

Fishermen can not afford this much uncertainty in the performance or service life of hooks as a sizable portion of their investment (about 5 to 20 % of the total cost of a hook and line fishing gear) goes into the purchase of fishing hooks. Since there are no well-defined standard methods for classifying fishing hooks, there is a pronounced need for a unified standard for designating fishing hooks.

Inspite of their historical and technical importance in the fishing sector, fishing hooks did not receive the required attention of researchers so far and very little is done on their classification, physical and mechanical properties, material composition, corrosion resistance and fishing performance of fishing hooks. Fishing hooks and their properties as a fishing gear have not received adequate attention in India also. Studies so far conducted in India are mainly focused on fishing efficiency of the hooks. Physical and mechanical properties, material composition, corrosion resistance and fishing performance of fishing hooks are not much studied. Details like different types of fishing hooks available in the country, their classification, sizes etc. are difficult to find and research on this line is almost absent in India. Studies on the basic physical properties, mechanical strength properties, corrosion resistance and durability are not much looked into. Whatever work that are made have now become out dated due to emergence of new models, materials and technologies as the introduction of new technologies and materials have significantly influenced modern-day fishing methods and practices (Hameed and Boopendranath, 2000).

Properties like hook shape, hook size/number, resistance to unbending force or hook failure under load etc. have a direct influence on the fishing performance of hook. The fishing hooks available to the fishermen are not uniform in their physical and mechanical properties and a high level of variation is seen in their quality and prices also. The difference in the material used for manufacture of hooks and the differences in manufacturing process, design etc. can be attributed to these variations in quality and performance (Anon, 2002). Since there is no standard way to express the physical strength, corrosion resistance and fishing efficiency of fishing hooks, it is difficult to compare fishing hooks.

In this context, a detailed study on the various properties of fishing hooks, their design aspects, physical and mechanical properties, chemical composition, corrosion resistance, comparative fishing performance etc. are greatly needed. This will ultimately help in the promotion of size and species selective, low energy hook and line fishing for the exploitation of untapped resources of the high seas and inland waters. Besides, the substitution of costly imported fishing hooks with less costly Indian hooks if possible would help to save considerable amount of foreign exchange.

Further, there is a scope for improving the existing hook designs and techniques. In order to realize all these, a detailed study of hook designs, their manufacturing process, mechanical and fishing performance etc. has to be under taken as such information is hard to find and most of the commercial manufactures will not disclose such information. This study is an attempt to make such information available so that further advancements can be made, especially in India. Hence this research work was carried out with the following objectives:

1.3.1. Objectives of the study

- To evaluate availability and cost of fishing hooks in India.
- To evaluate the physical and mechanical properties of different types and sizes of hooks.

- To standardise the hook numbering system.
- To correlate the mechanical strength with the chemical composition of hooks.
- To evaluate corrosion resistance of hooks and probable corrosion protection/prevention measures.
- To compare the fishing performance of hooks.

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REVIEW OF LITERATURE

Fishing hooks are among the simplest and the oldest of fishing gears. Due attention has not been given in the study of hooks and what ever information that are made available on the properties and performance of hooks by a handful of workers have now become out dated due to emergence of new models, materials and technologies. This calls for a detailed study on the various properties of present day fishing hooks. As a first step, a detailed review of the studies carried out on fishing hooks was undertaken. The literatures have been sourced from different libraries, abstract databases like the Aquatic Sciences and Fisheries Abstracts (ASFA) database, Science direct, the internet etc. The literature search produced a few documents describing work in India and abroad, giving an overview or basic aspect of the study topic.

It was found that unlike the studies on netting materials, very little is done on fishing hooks. Baranov (1976) has reported on the scarcity of research work on the different properties and quality of fishing hooks. Kenchington and Halliday (1994) have also reported that most of the published research works on fishing hooks are concerned with the catch rates achieved by different hook designs (Bjordal, 1983, 1987). Only a few reports are available on the properties and standards of fishing hooks (Andreev, 1963; Baranov, 1976, 1977; Ko and Kim, 1981; Kitano *et al.,* 1990; Varghese *et al.,* 1997; Thomas *et al.*, 2007; Edappazham *et al.*, 2008). Most of the remaining studies are found limited to the catching efficiency or size selectivity aspects (Takeuchi and Koike, 1969; Despande *et al.,* 1970; Kartha *et al.,* 1973; Ralston, 1982; Huse and

Fernö, 1990; Lokkeborg and Bjordal, 1992; Durai, 2003; Kumar, 2006). Studies on the basic physical properties, mechanical strength properties, corrosion resistance and durability are not much looked into. In this context, a review on the information available on various aspects of fishing hooks is made for further study and development.

2.1. Physical and mechanical properties of hooks

Very few studies have been carried out on the physical and mechanical properties of fishing hooks. Ko and Kim (1981) evaluated six types of hooks for assessing the force required for breaking and unbending due to plastic deformation of the material using dynamometer. The tests were carried out at a speed of 290 mm/min and 780mm/min respectively. They have also studied the dynamic forces acting on the fishing hook during hooking and hauling. Varghese *et al.* (1997) studied the physical properties, chemical composition and corrosion resistance of fishing hooks from five indigenous hook manufacturing firms and that of one imported brand (Mustad). They have carried out the unbending test of hooks by recording the load required for deformation equal to bite length. In their study they found that the indigenous hooks were poor in resisting deformation under load in contrast to imported brand and that the Indian hooks were more fragile compared to imported ones. According to Andreev (1963) the breaking load of the hook was independent of the shape and nature of hook. Practically hook failure occurs when the point move 60^o from its original position. The load required to deform the hook bend equal to the bite length or that required to deform the bend by 60^o from the original position or break occurring before attaining 60^o is measured (Anon, 2002). Edappazham *et al.* (2008) observed that unbending test could be used as an effective tool in analysing the mechanical properties of fishing hooks. They compared the physical and mechanical properties of three imported brands of fishing hooks with two indigenous brands. It was found that the indigenous brands of hooks were comparable with imported hooks in terms of physical and mechanical properties. This study also revealed that the wire diameter and the unbending force of fishing hooks are positively correlated.

2.2. Chemical composition

The chemical composition of the core material of the hook plays an important role in determining the mechanical strength of fishing hooks. Studies on the chemical composition of fishing hooks are found to be very limited. Chemical composition of Indian and imported hooks was evaluated by Varghese *et al.* (1997). The elemental make up of the core material of the hooks was analysed using Inductively Coupled Plasma Atomic Emission Spectrometer. They have reported that both types of hooks had almost similar chemical composition. Edappazham *et al.* (2008) compared the chemical composition of three imported brands of fishing hooks with two indigenous brands. They also did not find any significant difference in chemical constitution of Indian and imported hooks.

2.3. Corrosion resistance

Corrosion resistance, an important criterion in the quality evaluation of a hook, may vary depending on the type of the material, the type of the coating, fishing conditions, water temperature, pH value and type of bait. Only very few studies have been carried out on the corrosion resistance of fishing hooks (Thomas *et al.*, 2007). Corrosion resistance is generally assessed using salt spray chamber test (ASTM B 117 - 03, 2003). Varghese *et al.* (1997) have opined that 98 hours of salt spray exposure of fishing hook is equivalent to 365 days in sea water. The corrosion resistance of different fishing hook has been studied by Kitano *et al.*

(1990) and Varghese *et al.* (1997). The Indian hooks compared very well with the imported hooks in their tolerance to slat spray in the salt spray experiments comparing Indian hooks with imported hooks carried out by Varghese *et al.* (1997). Wuertz (2002) has described about a ‘Modified ASTM B-117 Salt Spray Test’ in which the fishing hooks were exposed in a salt spray cabinet for 21 days (504 hours) to compare the performance of two different rust preventive coatings used for hooks manufactured by Mustad and Sons A.S., Norway (http://www.mustad.no), one of the major group engaged in hook manufacturing.

Kitano *et al.* (1990) studied the effect of attaching nylon monofilament on corrosion resistance of fishing hooks. In this study, seawater immersion test and electric potential measurements were conducted for tuna hooks, using various anti-corrosive materials to evaluate their corrosion mechanism and resistance to corrosion. The results showed that the method of attaching aluminum to the fishhook was found to be most effective and even low-priced aluminum proved to be effective. The study pointed out that adopting this method could greatly reduce labour and expenses required to exchange and re-plating of the corroded hooks. Edappazham, *et al.* (2007) studied the effect of attaching snood wire on corrosion rate of fishing hooks. In this study it was found that rigging of metallic hooks using stainless steel snood wires increased the corrosion of fishing hooks, especially at the eye portion where the snood wire was attached.

2.4. Fishing performance

Hameed (1982) carried out experimental fishing operations using vertical longlines at different water depths to find out the swimming layers of shark. Selectivity of hooks in *Lethrinid* longline fishery of Thoothukudi coast, Tamilnadu (India) was studied by Durai (2003). In a similar study, the selectivity and efficiency of hooks in *Serranid* longline fishery of Thoothukudi coast was studied by Kumar (2006). In his study he has analysed the selectivity and fishing performance of six sizes of commonly used J-shaped (Round bent) fishing hooks with hook numbers 5 to 10. The hooking percentage observed for different species of *Serranid* fish ranged from 0.13 to 0.56%. He has reported that larger hook sizes had very good selectivity in capture of large sized *Serranids* while small sized hooks showed good selectivity in fishing small sized *Serranids*.

2.4.1. Hooking efficiency

The hooking efficiency is influenced by the size and species of the target fish. Hook efficiency can be expressed as the number of successful hooking divided by the number of attempts or number of fish caught divided by number of fish taking the bait (Number of bites). Hooking rate is generally expressed as the number of fish caught per hundred hooks (Gibson, 1979). Despande *et al.* (1970) studied the hooking rate and efficiency of 'Mustad' hook 4/0. Kartha *et al.* (1973) studied the effectiveness of round bent hooks (Mustad) of different denominations using different baits. The responses of cod (*Gadus morhua L.*) and haddock (*Melanogrammus aeglefinus L.*) to baited hooks were analysed by Huse and Fernö (1990) to determine their behaviour patterns, which could form the basis for improved longline hook design. The most important behaviour pattern observed for successful hooking of fish was when the fish swam away rapidly with the baited hook in its mouth, termed as the "rush" behaviour (Huse and Fernö, 1990). A hypothesis for hook design was formed, proposing that a longline hook with its point towards the line of pull would catch more fish than a typical Atlantic longline hook with its point parallel to the line of pull. Two experimental hooks conforming to this hypothesis were compared with a standard hook in fishing experiments. Sulochanan *et al.* (1989) have analysed the hooking rate of tuna in the Arabian Sea with particular reference to yellow-fin tuna, *Thunnus albacares*. In this study, the catch index for all tuna and that separately for yellow-fin tuna was 1.54% and 1.43% respectively.

George *et al.* (1991) experimented 4/0 round bent indigenous hooks along with imported Mustad hooks. They have compared the hooking rate of sharks for the two types of hooks and found that both are comparable. The studies were conducted from M. V. Saraswathy of CIFE, Bombay in and around Angrea Bank and off southwest Bombay. Studies by Jorgensen (1995) shows that long lines were up to 30 times more effective in catching large fish when compared to the trawls. The study of Olsen (1995) also reveals efficiency of long lines for catching deep water fish. The fishes captured by hook and line fishing are relatively large in size and have better quality. Prince *et al*. (2002) have compared the performance of circle hook and "J" hook in recreational catch-and-release fisheries for billfish. They have reported that circle hooks used on sailfish had hooking percentages that were 1.83 times higher compared with "J" hooks. Bacheler and Buckel (2004) have studied the influence of hook type on the catch rate, size, and injury of grouper in a North Carolina commercial fishery. In a fishery resource survey of the Indian Exclusive Economic Zone (EEZ) around Andaman and Nicobar Islands conducted by Fishery Survey of India (FSI) during August 1989 to December 2002, the overall hooking rate recorded for tuna hook was 1.85% (John *et al.*, 2005).

2.4.2. Hooking Mortality and Survival

Korakandy (2000) reported India's tremendous potential in recreational fisheries, especially in the state of Kerala as a result of the fast growing tourism industry. He pointed out the long tradition of recreational fishing in

India even before independence. There is a renewal of interest in recreational fishing due to the tourism development in the country. But recreation fishing needs to be introduced on a responsible manner as captured fishes are released subsequently in 'catch and release' type of recreation fishing. The survival of the released fish often depends on the severity of the wound and the handling of the catch. Fish caught by hooks are generally hooked in the mouth, particularly in the jaw or in the alimentary tract if the hooks are swallowed (Lokkeborg *et al.,* 1989; Huse and Fernö, 1990; Lokkeberg and Bjordal, 1992). Hook shape can be designed to decide the depth of penetrating the inside of the mouth of a particular species of fish. Injuries to internal organs as a result of deep hooking or hooking in locations other than the mouth significantly increase release mortality (Anon, 2003). Appropriate hook types have to be used for minimum mortality and to conserve fish stocks for continued fishing activities. The design of the hook itself, when used properly, prevents fish from being hooked in the gut, which reduces the mortality.

Circle hooks seem to be a promising type of hook to reduce release mortality (Anon, 2003). They can keep the hooked fish alive, till they are taken out. These hooks are designed to move to the corner of the fish's mouth and set themselves as the fish swims away. The more a fish is swimming away from the pull point, the more likely the hook will move to the rear corner of its mouth (Anon, 2005b). Significantly lower release mortality in striped bass when using non-offset circle hooks, as opposed to conventional "J" hooks is reported (Lukacovic, 1999, 2000, 2001, 2002; Lukacovic and Uphoff, 2002). Studies by Prince *et al.* (2002) on billfish, Skomal *et al.* (2002) on bluefin tuna, Falterman and Graves (2002) on yellowfin tuna, and Trumble *et al.* (2002) on Pacific halibut also showed significant decrease in release mortality while using circle hooks. Circle hooks can be used for reducing release mortality in rock bass (Cooke *et* *al.*, 2003). But the use of circle hooks on bluegill and pumpkinseed showed no significant benefit (Cooke *et al.,* 2003).

A study by Ayvazian *et al.* (2002) with five hook types on the mortality rate, injury type and injury location for fish to find out the short term mortality following catch and release angling of tailor fish (*Pomatomus saltatrix*) showed that treble hooks produce significantly higher mortality rate than single barbed and barb less hooks. Treble hooks cause multiple injuries and require increased handling time to disengage hooks from the multiple penetrations, most of which are superficial. Single barbed and barb less hooks even though causes a single injury, significant mortality is caused due to penetration of internal organs such as oesophagus, gills and stomach. Ganged hooks with/without terminal trebles cause jaw injury while barbed and barb less single hooks cause gill injury. Muoneke and Childress (1994) reported that single hooks, especially when used in conjunction with natural baits, resulted in higher mortality than treble hooks.

A review of the studies carried out on different aspects of fishing hook reveals that only very limited studies have been carried out on hooks in the Indian context, with the exception of studies on hooking efficiency. Besides, no data are available on the availability as well as properties of many of the hook types currently used in the field.

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Chapter - 3

MATERIALS AND METHODS

This study involved extensive collection of data and samples of a variety of fishing hooks and analysis of the collected data and samples for arriving at meaningful results. A detailed review of studies done and/or being carried out on fishing hooks was undertaken which formed the secondary data for this study. Diverse information available on various aspects of fishing hooks was gathered, studied and documented in detail which formed the basis for this study. A preliminary survey was conducted to assess the availability and present status of fishing hooks and their use in India. The different types and sizes of fishing hooks were collected from different parts of the country, covering all major fishing centres. Different parameters of the collected hooks were tested in the laboratory and evaluation of their performance was assessed in actual field conditions. This study was of multidisciplinary in nature, spanning into physical, mechanical, chemical and experimental fishing studies. The general methodology followed for this study is discussed in this chapter.

Area of the study, sample collection methods, procedures followed for the measurement of different properties of fishing hooks and sample preparation procedures for different analysis are described. Experimental procedures for the evaluation of mechanical strength, chemical composition, corrosion resistance and fishing performance of the fishing hooks studied are also outlined. Statistical methods followed for the analysis of the data are also explained. Detailed and specific information on the materials and methodologies specific to each aspect studied is given in the respective chapters.

3.1. Study area

This study covered all the major fishing centres in India. Fishing hook samples and data were collected from 54 major centers across the country. The states from which the samples were collected include Kerala, Tamil Nadu, Andra Pradesh, West Bengal, Assam, Karnataka, Maharashtra and Gujarat. Details are given in Chapter 4.

3.2. Sample and data collection

Hook samples were collected from different hook manufacturers, suppliers and shops from various parts of the country. The sample collection centers were selected based on the availability of fishing hooks and prevalence of hook fishing. Relevant information on availability, price and use of fishing hooks was collected through structured questionnaires. Detailed description of methodologies adopted for the sample and data collection is given in Chapter 4, section 4.2. A total of 282 denominations of fishing hooks coming under 7 imported brands, 7 Indian brands and 4 unbranded indigenous hooks were collected, catalogued and properties of each type of hook in each brand and size were measured and further analysed.

3.3. Evaluation of physical properties

The important physical dimensions of fishing hooks analysed were total length, bite length, gape, wire diameter and weight. These properties were measured as described in Chapter 5, section 5.2.1. For each parameter, mean value of ten samples was taken for the analysis.

3.4. Evaluation of mechanical property

Mechanical strength of the hooks was measured using unbending test. It is a modified form of conventional tensile test. It is also known as Mustad Bending Test (MB Test). The detailed methodology is given in Chapter 5, section 5.2.2.

3.5. Microstructural observations

The microstructural observations of the core material of hook specimens were made after polishing and etching with 5% nital solution (100 ml ethanol and 5 ml nitric acid) by optical microscopy (OM) (using 'Leica MZ16 A' Optical Microscope).

For the microstructural analysis, small portions of the hook shanks were cut from the hook. The surface coating on the cut portion were first filed off and polished up to 2000 grits serially from 320, 400, 600, 1000, 1200, 1500 and 2000 using Silicon Carbide (SiC) paper (Ashraf and Shibli, 2007). The surface was cleaned ultrasonically in acetone, washed with water and finally with Millipore water (Milli Q; 0.22 µm). The coupons were dried and the surface was etched by dipping in 5% nital solution for 60s. They were again washed with Millipore water and dried. The morphology of the surface was analysed by using optical microscopy.

3.6. Analysis of chemical composition

Chemical compositions of core material of the hooks were analysed as per ASTM E 415 - 99 (2005) except the carbon content. The carbon content was analysed by the combustion gravimetrical method as per ASTM E 352 - 93 (2000). Composition of the following important elements of the hook viz., Nickel (Ni), Manganese (Mn), Copper (Cu), Chromium (Cr) and Lead (Pb) were analysed using acid digest solutions by Inductively Coupled Plasma Atomic Emission Spectrometer (Optima 2000 DV Optical Emission Spectrometer from Perkin Elmer Instruments). Detailed description of methodologies adopted for the analysis of chemical composition is given in Chapter 6, section 6.2.1.

3.7. Analysis of corrosion resistance by using salt spray

General corrosion resistance of the hooks was analysed by using salt spray tests. The hooks were subjected to salt spray (salt fog) in a standard salt spray cabinet as per ASTM B117 standard (ASTM B 117 - 03, 2003) up to 300 h. The hooks were visually observed for the extent of corrosion at every 100 hours. After exposure in the salt spray chamber, the hooks were cleaned and dried. The hooks were then weighed to find out the weight lost during the test. From the weight loss, the percentage weight loss and corrosion rate were calculated. The detailed methodology is given in Chapter 7, section 7.2.1.2.

3.7.1. Surface Analysis

Surface of any metallic materials play an important role in corrosion prevention or propagation. Apart from that their surfaces evolve drastically as corrosion advances. The surface characteristics of the specimens were examined by optical microscopy (OM) ('Leica MZ16 A' optical microscope) and Scanning Electron Microscopy (SEM) (JEOL JSM-T330A Scanning Electron Microscope). The SEM images of fresh, unexposed and exposed hooks were recorded using Scanning Electron Microscope at 10keV. The images of the unexposed hooks were taken after cleaning the hooks with Millipore water and acetone. The images of hooks that were exposed in 5% NaCl were taken after cleaning the hooks as per ASTM G1 - 03 (2003).

3.8. Analysis of fishing performance

Fishing performance of the hooks was evaluated by experimental fishing using handline fishing gear identical with the handline configuration used by the artisanal fishermen in the study area.

The fishing hooks selected for the study were used as the terminal gear. Polyamide monofilament yarn of 0.8 mm diameter was used as the line. Different types of natural dead baits such as oil sardine, chicken waste and dough bait, the popular baits used in the study area were used to bait the hooks. The depth of operation was adjusted according to the water body where the gears were operated and also the targeted fish species. The baited handlines were cast concurrently in the same location. The number of bites, number of successful hooking, location of hooking injury on fish's body, severity of wound and the type of fish caught were recorded. Detailed description of methodologies adopted for this study is given in Chapter 8, section 8.2.

3.9. Statistical Analysis

All statistical analyses were performed using Statistical Package for the Social Sciences (SPSS version 12.0, SPSS, Inc., Chicago, IL) and test results were considered significant at the 95 % confidence level (i.e., $P < 0.05$). Erroneous and highly varied data were removed before analysis. Differences in unbending strength, corrosion resistance, fishing efficiency were analysed using analysis of variance (ANOVA). Significance levels were tested at the $P \leq 0.05$ level. Pearson's correlation analysis was used to compare the relationship between material composition and mechanical strength. Regression analysis was used to find out the inter dependence of different properties of hooks with the hook numbers.

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Chapter - 4

COST AND AVAILABILITY OF FISHING HOOKS IN INDIA

4.1. Introduction

Easy availability and reasonable pricing are important factors in popularization and promotion of any commodity. It is imperative that adequate information has to be available to take any policy decision on such issues. In the case of fishing hooks no such information is available in India on their availability and cost. Varghese *et al.* (1997) made use of imported branded and unbranded locally made fishing hooks in their studies. In their work, they considered the popular Norwegian branded hooks (Mustad brand) as the standard against Indian unbranded locally made fishing hooks. The Indian Standard IS: 9860 (Part I) – 1981 stipulates specifications for different fishing hooks such as single straight flat, single straight ringed, single kirbed flat, single kirbed ringed, double round, treble and single kirbed turned down ringed hooks to be used in India. Apart from these references no other information is found available regarding the availability and cost of fishing hooks in India. Hence a preliminary study on the availability and cost of fishing hooks was carried out.

4.2. Materials and Methods

A preliminary survey on the fishing hooks and line fishing was carried out as per Miyamoto (1962). Information on the availability, cost and use of different fishing hooks in India was collected through field visits and using structured questionnaires. Following questionnaire was used for collecting data and samples (Table 4.1.).

Table 4.1. Questionnaire used for the for collection of data and samples

Station:	**Date:**
1) General details	
Name and address of contact person:	
Gear Type & Time of Operation:	
Depth of operation:	
Local Name:	
Targeted sps.:	
2) Details of Fishing hook	
Type and size/Number:	
Material of construction:	
Brand name if any :	
Source :	
Indian/Imported/Unbranded:	
Cost/Price:	
Average Life span of hook:	

4.2.1. Selection of sample and data collection centres

The sample and data collection centres were selected based on the prevalence of hook fishing and also based on the availability of fishing hooks. A total of 54 major centers were selected for the collection of data and samples. A map showing the major sample collection centers selected is given in Fig. 4.1.

Fig. 4.1. Major sample collection centers

The following is the list of centres from where samples and data were collected:

Gujarat: Veraval, Mangrol, Porbander, Nava Bander, Dwaraka and Okha.

Maharashtra: Sasson Dock, Versova, Katha Bazaar and Pune.

Karnataka: Mangalore, Malpe and Uduppi.

Kerala: Vizhnjam, Valiyathurai, Marianad, Neendakara, Chelakkadu, Padanilam, Thottappally, Kattoor, Chellanum, Fort Cochin, Cochin harbour, Puthuvaypu, Munambam harbour, Kozhikkode, Elatur , Mahe, Thalassery, Mopla Bay, Kangangadu, Pallikkara, Achankovil river and Reservoirs of Palakkad and Thrissur districts.

Tamil Nadu: Enayam, Kadiapattinam, Muttom, Kanyakumari, Chinnamuttom, Manakkudi, Pallam, Manavalakurichi Nagercoil and Coimbatore.

Andra Pradesh: Vishakapatnam and Bheemlipatanam.

West Bengal: Contai, Ramnagar, Junput, Shankarpur, Mohana, Digha and Radha Bazaar.

Assam: Guwahati.

4.2.2. Sample collection

Fishing hooks of different types, sizes/numbers and brands were collected from different parts of the country, covering all the major fishing states in India, namely Assam, Andhra Pradesh, Gujarat, Karnataka, Kerala, Maharashtra, Tamil Nadu and West Bengal. The samples were collected from three different sources viz. directly from the manufacturers, from suppliers and shops in the fishing centres selected. Materials manufactured under major brands were collected directly from the manufacturer as far as possible as many fake products are available in the market in the name of reputed brands. The rest of the samples were collected mainly by visiting the concerned centre or supplier in person.

Collected samples were systematically categorized according to their brands, material, size/shape, source etc., coded, tagged and kept for further analysis of their properties. The various information collected about the availability and cost of fishing hook were analysed in detail to draw clear conclusions. For the comparison of prices of different hooks, the average cost of fishing hooks was calculated under each brand, type and size.

4.3. Results and Discussion

All the types of hooks used in the study area were made of steel and most of the hooks were nickeled or tinned. Hooks coated with blue or black polymer resins were also available. It was found that a large variety of fishing hooks, of varying quality and price manufactured under different brands, both imported and Indian, and unbranded locally made hooks are available in India. Hooks of different shape, size and make are used in fishing gears like long lines, drop lines, troll lines, pole and lines and hand lines at different parts of the country. A total of 282 types of hooks of different brand, size/number and material were collected as part of this study. They were composed of 7 imported brands, 7 Indian brands and 4 unbranded Indian hooks. Generally branded hooks are produced by large scale producers whereas unbranded hooks are mainly produced by small scale or cottage industrial units or individual blacksmiths.

Fishing hooks are locally named variously in different parts of the country. It is locally known as '*Choonda*' in Kerala and '*Choodai*' or '*Thoondel*' in Tamil Nadu. In hindi speaking regions it is known as '*Kanta*' whereas the fishing hook is called '*Borsi*' in West Bengal region.

4.3.1. Available types and size of hooks

It was found that round bent, kirby, limerick, circle hooks, tuna hooks and treble hooks are the major commercial types of fishing hooks available in India. The Round Bent hooks are the most widely used type of fishing hooks. It is used in almost all types of hook fishing. Both Kirby bent and Limerick hooks were found to be used mainly in inland freshwater bodies than in marine fishing. Circle hooks are available in India but are not at all used in commercial fisheries. Tuna hooks mostly are used in long lines targeting tuna. From hook size number 4/0 to 22 was available in Round Bent hooks (Table 4.5.), whereas, in Kirby bent available hook size starts from number 6/0 to 20, and in Limeric hooks, size from 8/0 to 10 was available. The available sizes of Circle hooks include number 8, 9, 10/0 and 11/0. Only hook number 1 and 2 were found to be available in Tuna hooks. Apart from the commonly available hook sizes, the manufacturers are ready to supply any standard size and type of fishing hooks if there is a considerably big demand for it.

4.3.2. Available brands

Branded hooks, both imported and Indian, and unbranded locally made fishing hooks were found to be used. Among branded hooks, there were seven major imported brands and seven Indian brands available at different parts of the country. Mustad-Key and Mustad -Crown (Norway) were the most widely used while few other imported brands such as VMC (France), Youvella and 3 Yacht (S.Korea), EW (Eagle wave Hooks, Japan) and The Iron Arm (UK) were also used in certain fishing centres (Table 4.2.). Brands such as Fish, Addya, Trishul-Viaadi, Lion (Pashupati), Elephant, Super Angler and Matuk were the branded Indian hooks in use (Table 4.3.).

Table 4.2. Imported branded hooks available in India.

Sl. No.	Brand Name	Country of origin
1.	Mustad-Key	Norway
2.	Mustad-Crown	Norway
3.	VMC	France
4.	Youvella	S.Korea
5.	3 Yacht	S.Korea
6.	Eagle wave Hooks	Japan
7.	The Iron Arm	United Kingdom

Table 4.3. Indian branded hooks.

Sl. No.	Brand Name
1.	Addya
2.	Trishul-Viaadi
3.	Fish
4.	Lion (Pashupati)
5.	Elephant
6.	Super Angler
7.	Matuk

Apart from the branded hooks, unbranded indigenous hooks are also used, especially in shark and tuna fishing. It was found that unbranded indigenous hooks from south India are popular among fishermen and are widely used within the country. It was made popular by the migratory fishermen from Thoothoor-Colachel region of Tamil Nadu who used to fish all along both west and east cost of India. These fishermen considered as experts in shark and tuna fishing are very enterprising and adventurous. It was observed that these fishermen commonly use unbranded locally made hooks made in areas like Elatur and Beypore in Kerala and Manvalakurichi in Tamil Nadu. They prefer the locally made hooks over branded hooks primarily due to the lower price tag.

Regional availability of different brands and types of hooks is given in Table 4.4. It was observed that major brands such as Mustad, Trishul-Viaadi and Addya are available in almost all parts of India where hook fishing is practiced.

Table 4.4. Availability of different fishing hooks in India

Sl. No.	Hook Brand	Hook types	Available Areas
	Imported		
1	Mustad-Key (Norway)	Round Bent, Kirby, Limerick, Circle hooks, Tuna hooks, Treble hooks	All major fishing centers through out India
2	Mustad –Crown (Norway)	Round Bent, Kirby, Limerick	All major fishing centers through out India
3	VMC (France)	Round Bent, Treble hooks	Kerala, TN, Gujarat, MH, WB
4	Youvella (S.Korea)	Round Bent	Kerala, TN, Gujarat, WB
5	3 Yacht (S.Korea)	Round Bent	Kerala, TN
6	Eagle Wave Hooks (Japan)	Round Bent, Kirby, Limerick	Kerala, TN, MH, WB
7	The Iron Arm (UK)	Round Bent	Karnataka
	Indian		
1	Trishul-Viaadi	Round Bent	All major fishing centers through out India
2	Addya	Round Bent, Kirby, Limerick,	All major fishing centers through out India

		Circle hooks, Tuna hooks, Treble hooks	
3	Fish	Round Bent, Limerick	Kerala, TN, MH, WB
4	Lion (Pashupati)	Round Bent	Kerala, TN
5	Elephant	Round Bent	Karnataka
6	Super Angler	Round Bent	TN, Karnataka, WB, Assam
7	Matuk	Round Bent, Limerick	TN, Karnataka, WB, Assam
	Unbranded		
	-	Round Bent, Circle hooks, Tuna hooks	Kerala, TN, Karnataka, Gujarat, MH, WB

** Note:- Acronyms used: TN (Tamil Nadu), MH (Maharashtra), WB (West Bengal)*

4.3.3. Cost of fishing hooks

Prices of fishing hooks were found to be highly varied from brand to brand and also between different types of hooks. The average cost of most commonly available hook types and sizes are given in Table 4.5. The prices are expressed as price of 100 hooks.

Table 4.5. Size and costs of fishing hooks available

Hook Types	Sizes	Cost (Rs. per 100 pcs)		
		Imported	Indian	Indigenous (Local)
	4/0	5579	2960	1500
	3/0	3230	1700	1200
	2/0	2341	1240	900
	1/0	1653	880	700
	1	1184	609	500
	2	1077	570	450
	3	560	325	400
	4	406	220	NA
	5	315	165	NA
Round Bent	6	240	110	NA
	7	165	90	NA
	8	140	75	NA
	9	115	55	NA
	10	90	45	NA
	11	80	40	NA
	12	75	35	NA

	13	60	30	NA
	14	55	28	NA
	15	40	20	NA
	16	40	20	NA
	17	40	20	NA
	18	40	20	NA
	19	40	20	NA
	20	40	20	NA
Round Bent				
	22	40	NA	NA
	6/0	2900	1740	NA
	5/0	2650	1590	NA
	4/0	2390	1435	NA
	3/0	2130	1270	NA
	2/0	1870	1125	NA
Kirby Bent	1/0	1610	960	NA
	1	1350	810	NA
	2	1090	650	NA
	3	830	500	NA
	4	700	420	NA
	5	640	385	NA
	6	516	320	NA
	7	407	240	NA

	8	315	190	NA
	9	232	140	NA
	10	187	115	NA
	11	158	95	NA
	12	130	80	NA
Kirby Bent	13	119	70	NA
	14	105	60	NA
	15	95	60	NA
	16	80	50	NA
	17	80	50	NA
	18	80	40	NA
	19	60	40	NA
	20	60	40	NA
	8/0	NA	300	NA
	7/0	390	225	NA
	6/0	228	150	NA
	5/0	200	110	NA
Limerick Bent	4/0	190	100	NA
	3/0	110	60	NA
	2/0	102	55	NA
	1/0	94	50	NA
	1	59	40	NA

	2	57	30	NA
	3	48	30	NA
	4	46	25	NA
	5	46	25	NA
	6	44	25	NA
	7	42	25	NA
	8	29	25	NA
	9	33	25	NA
	10	30	25	NA
Circle Hooks				
	8	500	NA	NA
	9	660	NA	NA
	10/0	720	NA	NA
	11/0	800	NA	NA
Tuna Hooks				
	1	NA	NA	400
	2	NA	700	500

** Note:- Acronym used: NA (Data Not Available).*

The prices of imported brands of hooks were found to be double that of Indian brands and three fold that of unbranded locally made hooks. Further, it was found that in the year 2008-09, India has imported about Rs. 5.83 crores worth of fishing hooks and tackles (GOI, 2009). The price of same size and type of fishing hook of a brand is highly varied from one place to another. At some centers the hooks were sold at MRP (Maximum Retail Price) and in some other centers they were sold at lower price than the MRP. It was also observed that when the hook is sold in loose, they are even sold at double the price of actual MRP by small merchants.

The cost of fishing hook is an important component in the total expenditure on the gear. In many cases, the expenditure incurred on fishing hooks alone can grow to dramatic levels. Hook loss due to broken lines, physical damage of hooks, damages caused by corrosion etc. adds to the cost. The rate of hook loss is estimated as high as 3% per operation in shark long-lining operation (Anderson and Waheed, 1990) and 1.31% in snapper longlining (Willis and Millar, 2001). In their study it was assumed that most of this damage was done by sharks, although large billfish may also have been responsible. More hooks were seen to be lost whenever more sharks were caught. However, they admit that shark catches could have been increased by using strong metallic chain rather than wire leaders.

The vast availability of hooks of Indian brands which are much cheaper than their imported counter parts show that if the imported hooks can be substituted with local hooks and much foreign exchange can be saved besides easing the burden of fishermen. However, for this a thorough understanding of the properties, as well as fishing performance of different hooks is required. Hence, this study involving the comparative assessment of all the aspects of Indian and imported hooks was undertaken.

4.4. Conclusions

Diverse types and sizes of fishing hooks were available at various parts of the country under imported, indigenous brands and unbranded categories. The cost of imported brands of hooks was found to be very high compared to the indigenous brands of the same size. Diverse types and sizes of fishing hooks were available apart from the diversity in number of brands. A detailed database on the cost and availability of different fishing hooks available in India was prepared based on the data and samples collected as part of the present study from various parts of the country.

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Chapter - 5

PHYSICAL AND MECHANICAL PROPERTIES

5.1. Introduction

Properties like hook shape, hook size/number and resistance to unbending force or hook deformation/failure under load have a direct influence on the fishing performance of a hook. The fishing hooks available to the fishermen are not uniform in their physical and mechanical properties and a high degree of variation is seen in their quality between different brands. These variations could be attributed to difference in the steel wire used for manufacture of hooks and differences in hook manufacturing process (Baranov, 1976; Anon, 2002). Fishing hooks are subject to forces (loads) of varying magnitude when used for fishing and the mechanical strength of the hook is an important factor for successful fishing. It is more critical in fishing of fast moving large fishes like tuna and sharks. These fishes transfer high amounts of kinetic energy to the hook while hooking and this could lead to hook failure, which results in loss of catch.

Only very few studies have been conducted to analyse these physical and mechanical properties of fishing hooks. Ko and Kim (1981) tested six types of hook for breaking and unbending due to plastic deformation of the material using dynamometer. They also studied the dynamic forces acting on the fishing hook during hooking and hauling. Most of the studies carried out on hooks in India were focused towards fishing efficiency of different hooks (Despande *et al.*, 1970; Kartha *et al.*, 1973 and George *et* *al.*, 1991). Varghese *et al.* (1997) studied the physical and mechanical properties as well as corrosion resistance of fishing hooks from five indigenous hook manufacturing firms and that of one imported brand. They have carried out unbending test of hooks by recording the load required for deformation of the hook bend.

There are different imported brands, indigenous brands and unbranded hooks available in the Indian market. The indigenous brands are competing directly with a few major imported brands. New brands and improved hooks produced using advanced technology are entering the market very often. Since the physical and mechanical strength properties of a hook is not reflected in any methods of designating fishing hook, it is difficult to compare between different brands of fishing hooks. Also, there are no standard methods available to test the mechanical strength of fishing hook. Often the fishermen have to depend on their experience while selecting a fishing hook and they have to risk if they want to try a new hook. So a comparative database would help the fishermen in selecting the fishing hook with optimum quality features, better mechanical properties and performance. Here an attempt is made to analyze and catalogue the physical and mechanical strength properties of indigenous and imported hooks.

5.2. Materials and Methods

Physical properties and mechanical strength of all the 282 denominations of fishing hooks collected, under 7 imported brands, 7 Indian brands and 4 unbranded indigenous hooks were studied. Properties of each type of hook in each brand and size were measured and further analysed.

5.2.1. Evaluation of physical properties

The physical dimensions of the hooks were measured as per Indian Standard: 9860 (Part I) - 1981. Total length, bite length, gape, wire diameter and weight were the important properties analysed. Physical dimensions like total length, gape and bite length were measured by placing the hook on a graph paper and taking the values from the graph coordinates. Total length is measured from a point immediately behind the hook eye to the bend of the hook. Gape is measured as the distance between the point and the hook shank. Bite length is measured as the vertical distance from the point to the bend of the hook. Wire diameter measurement of fishing hook was taken on the round unforged portion of the shank using a micrometer (Mitutoyo, d=0.01mm). Weight of the hooks was recorded using a high accuracy electronic balance (Sartorius BP211D, d=0.01mg), by weighing ten hooks and taking the mean weight.

5.2.2. Evaluation of mechanical property

Unbending resistance of fishing hook was taken as a measure of mechanical strength in their functional form (Edappazham *et al*., 2008). Unbending test is a modified form of conventional tensile test. It is also known as Mustad Bending Test (MB Test). In this test the force required by the hook bend to develop a deformation equal to its bite length or to break the hook was measured using Universal Testing Machine (UTM). In this study, the unbending resistance tests were carried out using two Shimadzu (Japan) make UTMs (Shimadzu AG-I 10kN and Shimadzu AG-IS 250kN). The 250kN UTM was used for large sized hooks above number 1. A cross head speed of 25 mm/min was used for testing as per Varghese *et al.* (1997) (Fig. 5.1.). This test gives a measure of the force, a hook bend can withstand. The deformation of hook bend equal to bite length was taken as the standard as any deformation beyond this point will render it useless for fishing (Anon, 2002).

Fig. 5.1. Unbending test of fishing hook using UTM

In unbending resistance test, the hook to be tested was mounted between the grips of the UTM and it was pulled by a large hook having larger wire diameter. Hooks were subjected to deformation under gradually increasing load and the load exerted on the hook is monitored using Trapezium software interfaced with the UTM. The load required to instill a deformation of the hook bend equal to its bite length was taken for further analysis. Mean value of ten readings was taken for analysis. The results of the unbending test were verified with the feed back taken from fishermen about the performance of fishing hooks under use. The correlation of unbending strength with the wire diameter and weight of the hook was also evaluated.

5.2.3. Comparison of unbending load of Indian and imported hooks

In this study, a comparative analysis was carried out on the physical and mechanical strength properties of five major brands of round bent hooks. Number 7 size round bent fishing hook was selected for the comparative study, as it is widely available and commonly used by the fishermen for catching fishes like tuna and medium sized fishes. These are three imported brands, coded as FB-1, FB-2 & FB-3 and two indigenous brands, coded as IB-1 and IB-2. The dimensional characteristics and unbending force as tensile load for deformation of the hook bend equal to its bite length were also investigated.

5.2.4. Standardisation of hook numbering system

The data on the physical properties of the fishing hooks such as gape, length, diameter and weight were analysed statistically to arrive at a standard. Different parameters like dimensions and mechanical strength of different hook types were grouped according to their hook numbers. Erroneous and highly varied data were removed before analysis following 2d method (Dixon, 1950). The inter dependence between the different parameters was studied using regression analysis.

5.2.5. Statistical analysis

The deformation load equal to bite length values were analysed using univariate analysis of variance. The correlation of gape width with hook number, weight of hook, diameter, length and bite, unbending force with the diameter and weight of the hooks were analysed using Pearson's correlation analysis. Regression analysis was used to find out the inter dependence of different properties of hooks with the hook numbers.

5.3. Results and Discussion

5.3.1. Evaluation of physical and mechanical properties

Physical properties like gape, hook wire diameter, length of the hook, bite length and weight of each type of hook in each brand and size were measured. The mean value of ten replicates tested for each type and size irrespective of brand was calculated. A database on the physical properties of the hooks and mechanical strength in terms of the force in Newton (N) are given in the Tables 5.1. to 5.5.

In round bent hooks, properties like gape, diameter and bite did not show significant variation between brands. In the case of length and weight in larger hooks, the values showed wide variation. In Kirby bent hooks, the data did not show much variation between brands of same hook size. Similarly, in Limerick hooks, very nominal variation was observed between brands of same hook size. No significant variation was observed among different brands of hooks tested with respect to dimensional characteristics such as total length, hook wire diameter, gape and bite. However, significant difference was noticed in their resistance towards unbending viz., deformation equal to bite length ($P<0.05$).

Table 5.1. Physical and mechanical properties of round bent hooks.

Hook #	Gape (mm)	Wire Diameter (mm)	Length (mm)	Bite (mm)	Weight (g)	Unbending Load (N)
4/0	50.93 ±1.78	5.74 ±0.53	132.07 ± 12.95	56.20 ±1.31	47.32 ±13.79	4453.70 ±316.44
3/0	43.03 ±4.59	4.96 ±0.07	110.83 ±7.58	47.20 ±3.33	29.17 ±3.36	3411.82 ±394.26
2/0	38.03 ±1.79	4.85 ±0.44	93.55 ±6.14	43.23 ±2.06	23.44 ±3.47	3005.34 ±380.69
1/0	32.97 ±2.89	4.39 ±0.57	83.23 ±8.31	37.87 ±3.31	16.78 ±2.75	2149.51 ±845.47

1	30.50 ±0.45	3.79 ±0.50	76.48 ±2.85	34.98 ±0.62	11.85 ±3.26	1824.06 ±297.51
2	26.25 ±3.02	3.38 ±0.43	69.05 ±2.40	31.48 ±1.53	8.47 ±2.49	1296.02 ±178.69
3	24.48 ±1.00	3.21 ±0.55	63.10 ±3.26	28.48 ±2.47	7.06 ±2.90	1111.88 ±498.66
4	21.13 ±1.71	2.57 ±0.08	54.98 ±1.68	24.23 ±1.70	3.85 ±0.38	688.79 ±288.65
5	19.04 ±0.65	2.33 ±0.06	49.76 ±3.02	21.71 ±1.02	2.90 ±0.31	635.71 ±153.74
6	17.47 ±1.11	2.03 ±0.03	44.53 ±0.93	19.34 ±1.08	1.94 ±0.08	513.28 ±102.33
7	15.43 ±0.44	1.85 ±0.08	39.91 ±1.05	17.23 ±0.75	1.43 ±0.16	443.92 ±99.51
8	14.13 ±0.65	1.63 ±0.02	35.70 ±0.88	15.73 ±0.38	1.00 ±0.03	334.72 ±89.32
9	12.60 ±0.44	1.45 ±0.03	32.21 ±1.00	13.84 ±0.37	0.72 ±0.05	241.03 ±52.77
10	11.27 ±0.35	1.29 ±0.05	29.54 ±0.81	12.63 ±0.29	0.51 ±0.04	195.34 ±32.73
11	10.19 ±0.49	1.20 ±0.05	26.86 ±0.81	11.56 ±0.35	0.41 ±0.04	151.04 ±37.24
12	9.26 ±0.30	1.10 ±0.07	23.86 ±0.59	10.32 ±0.36	0.31 ±0.04	139.28 ±31.13
13	8.43 ±0.39	1.04 ±0.05	21.40 ±0.62	9.56 ±0.43	0.25 ±0.03	117.47 ±29.95
14	7.73 ±0.81	0.92 ±0.04	19.58 ±0.80	8.38 ±0.37	0.18 ±0.02	94.98 ±16.32
15	6.84 ±0.49	0.86 ±0.03	17.74 ±0.49	7.59 ±0.53	0.14 ±0.01	87.36 ±16.53
16	6.36 ±0.37	0.82 ±0.02	16.80 ±0.87	7.10 ±0.36	0.12 ±0.01	69.30 ±16.99
17	5.79 ±0.27	0.77 ±0.02	14.37 ±2.06	6.50 ±0.15	0.10 ±0.01	70.13 ±9.07
18	4.99 ±0.42	0.71 ±0.04	12.73 ±1.45	5.98 ±0.41	0.07 ±0.01	52.89 ±13.54
19	5.00 ±0.00	0.69 ±0.02	11.74 ±1.98	5.62 ±0.29	0.07 ±0.01	54.24 ±12.82
20	4.40 ±0.31	0.65 ±0.02	11.51 ±0.41	5.11 ±0.24	0.06 ±0.00	44.39 ±10.61
22	4.00 ±0.00	0.59 ±0.01	9.90 ±0.32	5.00 ±0.00	0.04 ±5.10	44.61 ±5.10

Physical properties of ten sizes of Mustad round bent hooks studied by Varghese *et al.* (1997) are found to be comparable with the properties of same sized hooks in this study. However, wide variation was seen in the mechanical strength. The deformation load for 3/0 round bent hook was 1377.28 N in their study, whereas in the present study it was 3411.82 N for the same sized hook. Comparisons of properties of hooks in other denominations also show the same trend. The indigenous hooks studied by Varghese *et al.* (1997) can not be directly compared with hooks in the present study as the hook numbers used in indigenous hooks are not standardized.

Table 5.2. Physical and mechanical properties of Kirby bent hooks.

Hook #	Gape (mm)	Dia (mm)	Length (mm)	Bite (mm)	Weight (g)	Unbending Load (N)
6/0	23.50 ±0.02	2.94 ±0.08	51.40 ±0.17	27.10 ±0.53	5.75 ±0.63	1550.03 ±209.10
5/0	20.10 ±0.10	2.66 ±0.05	44.40 ±0.40	24.70 ±0.57	4.12 ±0.56	1579.91 ±224.34
2/0	15.00 ±0.27	1.84 ±0.03	31.50 ±1.10	16.90 ±0.12	1.41 ±0.15	469.83 ±155.90
1	31.70 ±0.55	3.69 ±0.48	83.30 ±0.30	35.50 ±1.04	13.16 ±0.92	1805.02 ±118.40
3	26.30 ±0.05	3.03 ±0.07	62.70 ±0.54	28.80 ±1.33	7.26 ±0.66	1206.88 ±132.52
4	22.90 ±0.02	2.67 ±0.16	54.50 ±0.34	24.60 ±0.93	4.77 ±0.45	1058.83 ±108.70
5	20.60 ±0.85	2.35 ±0.18	51.65 ±0.07	21.90 ±0.42	3.20 ±0.88	611.97 ±119.90
6	16.93 ±0.30	2.01 ±0.03	45.88 ±1.38	18.80 ±1.35	1.91 ±0.11	493.75 ±244.56
7	13.90 ±3.94	1.62 ±0.38	34.90 ±11.98	15.22 ±4.24	1.12 ±0.54	282.00 ±111.43
8	14.40 ±0.94	1.61 ±0.04	36.93 ±0.78	15.65 ±0.83	1.01 ±0.10	240.69 ±41.73
9	12.85 ±0.87	1.47 ±0.03	34.00 ±0.74	13.93 ±0.49	0.76 ±0.08	203.76 ±13.25
10	11.53 ±0.46	1.33 ±0.07	30.27 ±0.46	12.70 ±0.36	0.54 ±0.05	175.66 ±11.43
11	10.65 ±0.47	1.22 ±0.05	28.43 ±1.11	11.68 ±0.42	0.45 ±0.07	145.90 ±4.06

12	9.65 ±0.47	1.14 ±0.05	24.60 ±0.70	10.70 ±0.52	0.35 ±0.05	129.67 ±7.53
13	8.58 ±0.42	1.07 ±0.05	22.50 ±0.39	9.68 ±0.29	0.27 ±0.04	118.91 ±2.84
14	7.75 ±0.07	0.99 ±0.01	20.25 ±0.78	8.45 ±0.78	0.22 ±0.03	109.95 ±4.32
15	7.15 ±0.07	0.88 ±0.01	18.30 ±0.42	7.35 ±0.92	0.16 ±0.01	91.11 ±0.68
16	6.50 ±0.00	0.82 ±0.01	17.55 ±0.21	6.90 ±0.99	0.13 ±0.01	60.50 ±12.85
17	6.90 ±0.01	0.91 ±0.02	18.70 ±0.56	6.80 ±0.90	0.18 ±0.04	72.50 ±2.43
18	5.00 ±0.00	0.72 ±0.01	14.85 ±1.20	5.95 ±0.49	0.08 ±0.01	61.30 ±10.72
20	4.00 ±0.00	0.67 ±0.07	12.60 ±0.91	4.30 ±0.42	0.06 ±0.04	54.84 ±1.30

Table 5.3. Physical and mechanical properties of Limerick hooks.

Hook #	**Gape (mm)**	**Dia (mm)**	**Length (mm)**	**Bite (mm)**	**Weight (g)**	**Unbending Load (N)**
8/0	21.30 ±0.43	2.04 ±0.05	60.40 ±0.84	20.80 ±1.06	2.33 ±0.35	464.35 ±107.05
7/0	19.05 ±0.35	1.90 ±0.11	53.05 ±1.06	17.95 ±1.06	1.81 ±0.26	388.94 ±91.44
6/0	16.67 ±0.21	1.63 ±0.01	46.93 ±1.17	15.30 ±0.82	1.17 ±0.03	324.62 ±87.04
5/0	15.37 ±0.60	1.44 ±0.01	44.07 ±1.31	13.33 ±0.95	0.84 ±0.02	256.50 ±49.22
4/0	14.16 ±1.31	1.43 ±0.22	40.32 ±1.56	13.16 ±1.63	0.84 ±0.37	287.22 ±157.05
3/0	13.70 ±0.36	1.34 ±0.25	35.73 ±1.12	12.27 ±1.67	0.67 ±0.34	263.85 ±128.97
2/0	11.83 ±0.45	1.22 ±0.18	32.53 ±0.25	10.73 ±1.53	0.50 ±0.19	229.82 ±85.94
1/0	10.50 ±0.30	1.10 ±0.13	29.30 ±0.17	9.87 ±1.17	0.36 ±0.12	179.91 ±70.48
1	9.64 ±0.43	1.02 ±0.08	25.38 ±0.29	9.18 ±0.54	0.27 ±0.06	143.38 ±43.87
2	9.06 ±0.77	0.96 ±0.08	22.80 ±0.72	8.66 ±0.40	0.22 ±0.04	124.69 ±41.11
3	8.08 ±0.54	0.88 ±0.06	20.36 ±0.64	7.98 ±0.43	0.17 ±0.03	108.43 ±25.70
4	7.56 ±0.85	0.85 ±0.05	18.38 ±0.48	7.28 ±0.54	0.14 ±0.02	101.49 ±20.44

5	6.75 ±0.47	0.81 ±0.05	17.08 ±0.51	6.78 ±0.43	0.12 ±0.02	89.24 ±19.02
6	6.17 ±0.21	0.74 ±0.03	15.57 ±0.72	6.07 ±0.31	0.09 ±0.01	69.21 ±11.42
7	5.60 ±0.17	0.71 ±0.06	14.83 ±0.50	5.77 ±0.59	0.07 ±0.01	61.72 ±10.65
8	5.27 ±0.31	0.66 ±0.03	13.60 ±0.89	5.20 ±0.46	0.06 ±0.00	44.61 ±6.89
9	4.28 ±0.88	0.63 ±0.06	11.80 ±1.44	4.33 ±0.53	0.05 ±0.01	37.58 ±3.08
10	3.87 ±0.80	0.58 ±0.04	10.73 ±0.70	4.10 ±0.44	0.04 ±0.01	37.79 ±12.43

Table 5.4. Physical and mechanical properties of circle hooks.

Hook #	**Gape (mm)**	**Dia (mm)**	**Length (mm)**	**Bite (mm)**	**Weight (g)**	**Unbending Load (N)**
11/0	22.67 ±0.58	2.38 ±0.01	35.67 ±0.58	20.00 ±0.00	2.74 ±0.01	668.24 ±24.63
10/0	19.00 ±0.00	2.35 ±0.01	28.70 ±0.58	17.00 ±0.00	2.40 ±0.01	566.34 ±153.28
8	21.80 ±0.00	2.36 ±0.00	32.10 ±0.58	19.50 ±0.58	2.62 ±0.02	730.65 ±39.90
9	18.60 ±0.58	2.35 ±0.00	28.30 ±0.58	18.10 ±0.00	2.39 ±0.00	814.29 ±41.56

Table 5.5. Physical and mechanical properties of tuna hooks.

Hook #	**Gape (mm)**	**Dia (mm)**	**Length (mm)**	**Bite (mm)**	**Weight (g)**	**Unbending Load (N)**
1	28.90 ±0.88	5.20 ±0.03	59.70 ±1.06	34.20 ±0.79	19.95 ±0.16	2085.61 ±212.66
2	20.00 ±0.01	4.95 ±0.02	52.00 ±0.01	30.00 ±0.03	13.68 ±0.02	1946.26 ±52.30

It was found that the physical dimensions of Kirby bent hooks were comparable to that of round bent hooks of the same size. On statistical analysis it was found that the gape width of round bent hooks is significantly (P<0.05) correlated to that of Kirby bent hooks (Fig. 5.2.). Whereas the dimensions of Limerick hooks did not match with that of corresponding round bent hook.

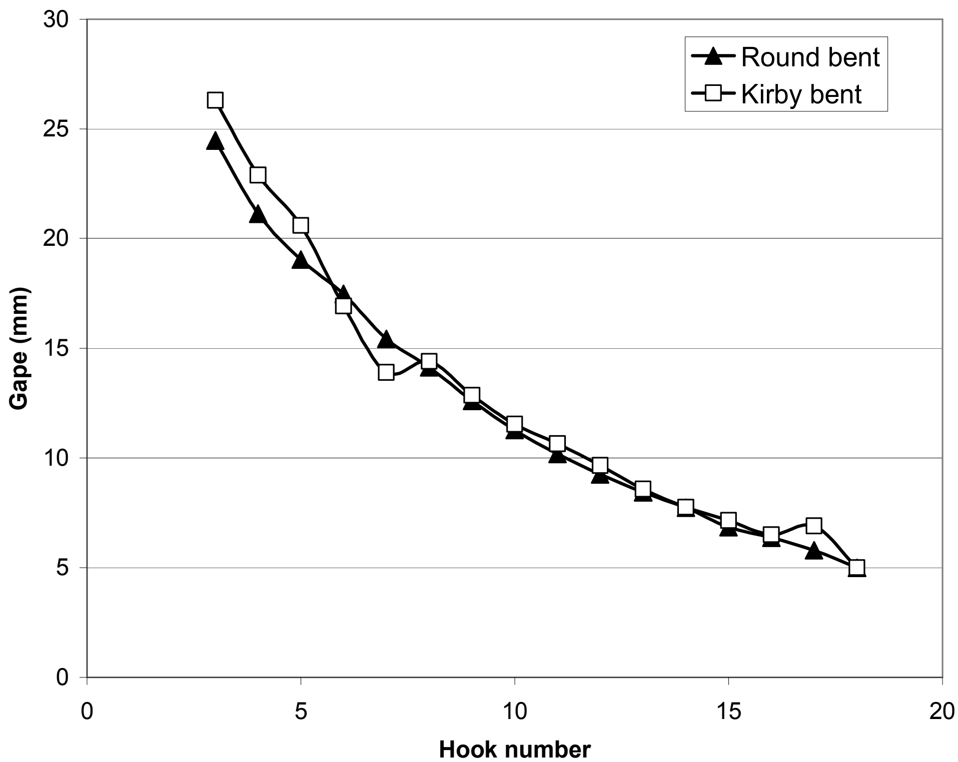

Fig. 5.2. Comparison of gape width of round bent and Kirby hooks.

The physical dimensions of Limerick hooks were further analysed and compared with that of round bent hooks. Remarkably it was found that the dimensions of Limerick hook sizes corresponds with that of another round bent hook size in a systematic way. For instance, number 8/0 Limerick hook is found to be equivalent to number 4 round bent hooks, like wise 7/0 Limerick hook is equivalent to number 5 round bent hooks and 6/0 Limerick hook is equivalent to number 6 round bent hooks. This relationship between different hook sizes of Limerick and round bent hooks is shown in Fig. 5.3.

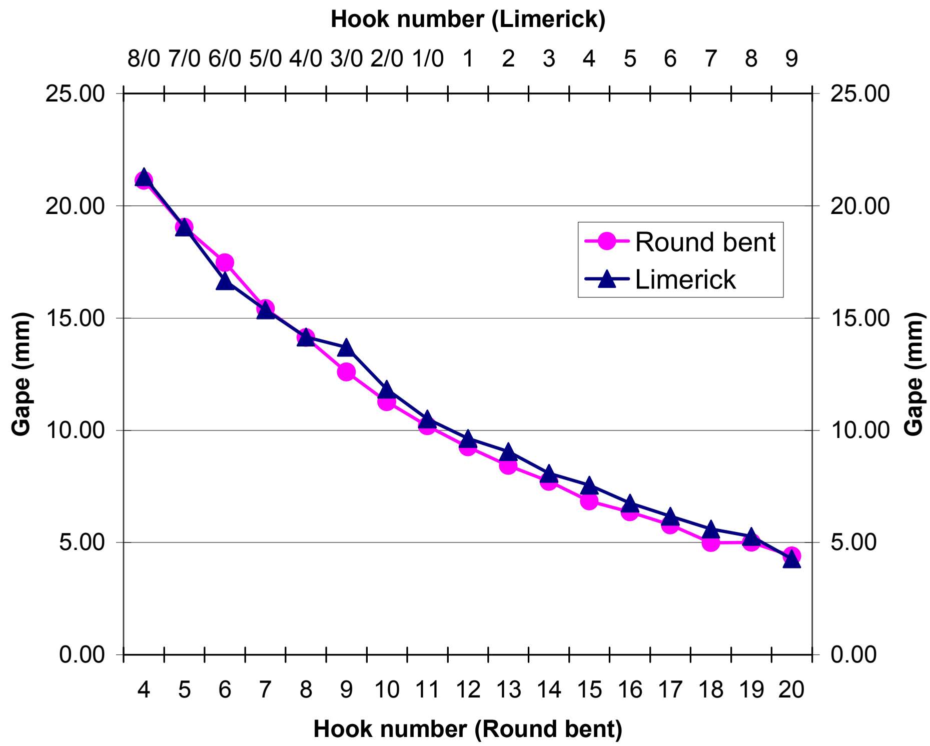

Fig. 5.3. Comparison of hook number and gape width of round bent and Limerick hooks.

5.3.2. Comparison of unbending load of Indian and imported hooks

The chemical composition of the core material and physical properties of the hooks studied are given in Table 5.6.

Table 5.6. Chemical composition and physical properties of fishing hooks studied.

	FB-1	FB-2	FB-3	IB-1	IB-2
Chemical composition (wt. %)					
Manganese (Mn)	0.51	0.62	0.64	0.76	0.65
Nickel (Ni)	0.02	0.04	0.06	0.01	0.01
Copper (Cu)	0.01	0.08	0.07	0.03	0.02
Chromium (Cr)	0.02	0.02	0.04	0.10	0.01
Carbon (C)	0.57	0.76	0.69	0.83	0.76
Physical properties					
Total Length (mm)	41.70	40.00	39.00	39.50	40.30
Gape (mm)	15.00	15.90	15.40	15.10	15.10
Bite (mm)	16.90	17.50	17.30	17.00	16.10
Wire Diameter (mm)	1.824	1.817	1.819	1.861	1.842

The brand FB-1 had a total length of 41.70 mm; the highest value in total length and it was lowest for FB-3 (39.00 mm). All the five types of hooks had almost uniform hook wire diameters ranging from 1.817 mm to 1.861 mm and variation was insignificant. In gape length, the highest value was for FB-2 at 15.90 mm and lowest was for FB-1 (15.00 mm). Similarly, the bite length was maximum for the brand FB-2 (17.50 mm) and minimum for IB-2 (16.10 mm). No significant variation was observed among the five types of hooks studied with respect to dimensional characteristics such as total length, hook wire diameter, gape and bite. However, the mechanical strength as resistance towards unbending of the fishing hooks studied were highly varied.

The unbending force of the five types of hook is shown in Fig. 5.4. Out of the five types of hooks, the indigenous brand IB-1 recorded the highest unbending force, 275.9N while IB-2 recorded the least (Fig. 5.4.). The IB-1 was followed by FB-1, FB-3, FB-2 and IB-2 respectively.

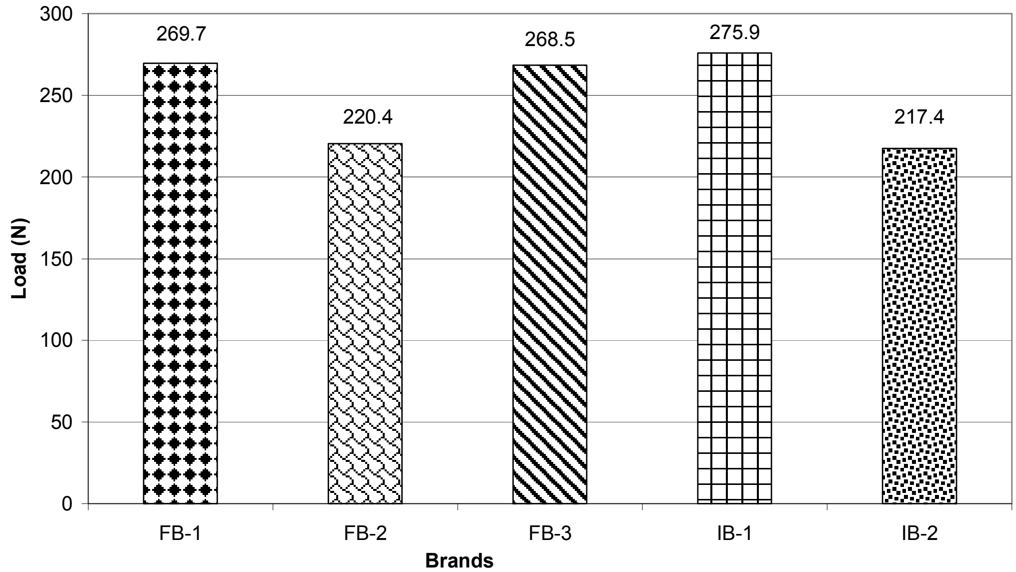

Fig. 5.4. Comparison of unbending force of fishing hooks investigated.

On statistical analysis, brand FB-1 was found to be significantly different from brands FB-2 and IB-2 ($P<0.05$). Similarly brand FB-2 was significantly different from FB-3 and IB-1, brand FB-3 was different from IB-2 and brand IB-1 was significantly different from IB-2 in terms of the load required for deformation equal to bite length. The inter dependence of the unbending force with hook wire diameter was analysed and it was found that the unbending force of fishing hooks is positively correlated with their wire diameter. A graphical representation of the correlation between the hook wire diameter and the unbending load is given in Fig. 5.5.

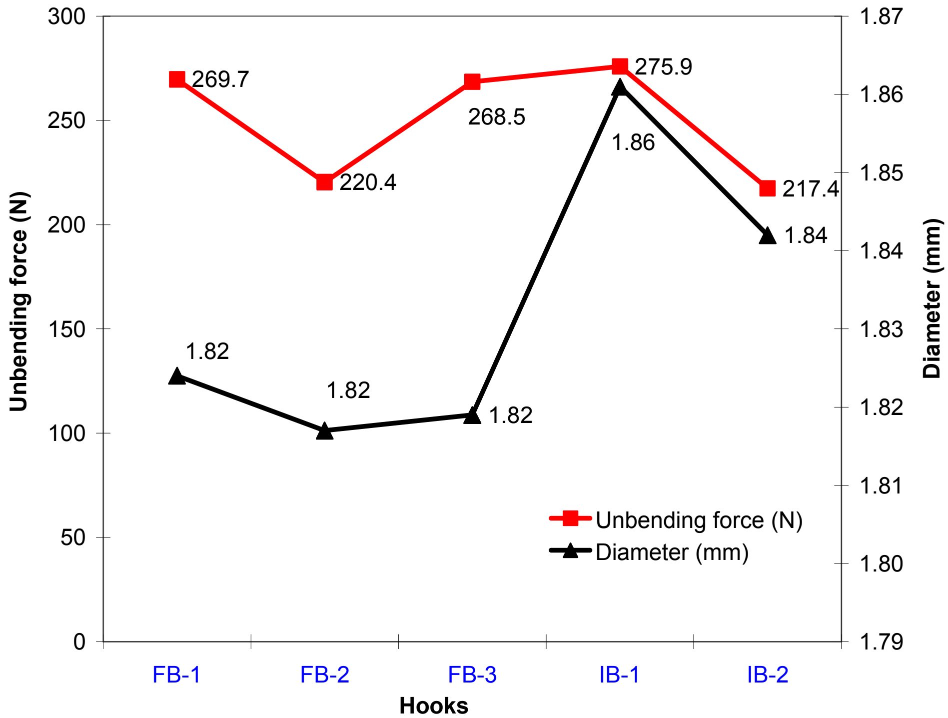

Fig. 5.5. Correlation of unbending force and wire diameter of fishing hooks investigated.

Similarly the relationship between weight of the hook and load for deformation equal to bite length was also analysed (Fig. 5.6.). It also showed positive correlation between the two parameters.

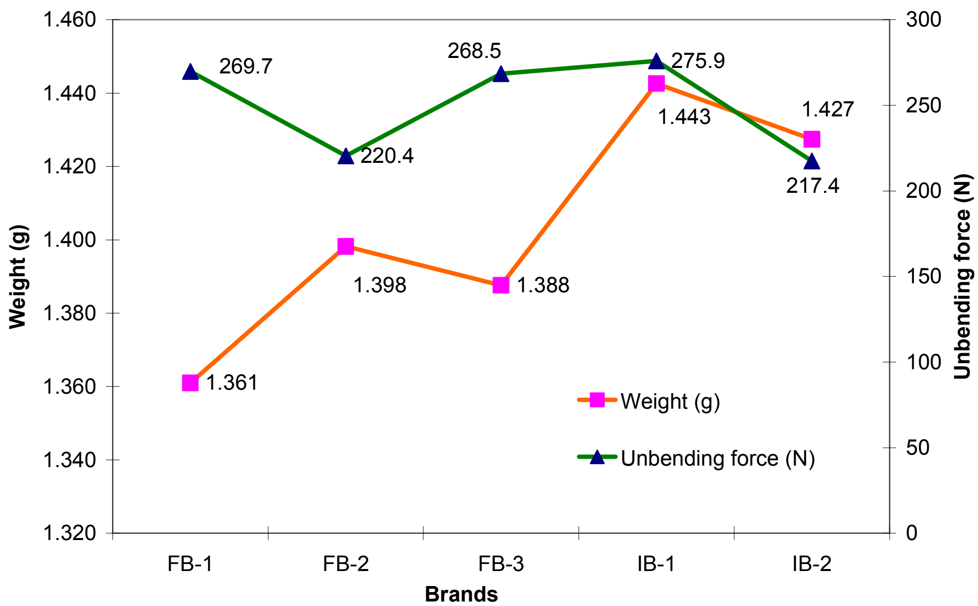

Fig 5.6. Correlation of unbending force and weight of fishing hooks investigated.

The microstructure of the hooks was studied using light microscopy and it was found that the hooks with high mechanical strength had a uniform fine grain-sized microstructure when compared to IB-2 – the hook with lowest mechanical strength (Fig. 5.7.). This fine arrangement of metal matrix could be the reason for their enhanced unbending resistance. This fine grained microstructure can be achieved through proper heat treatments.

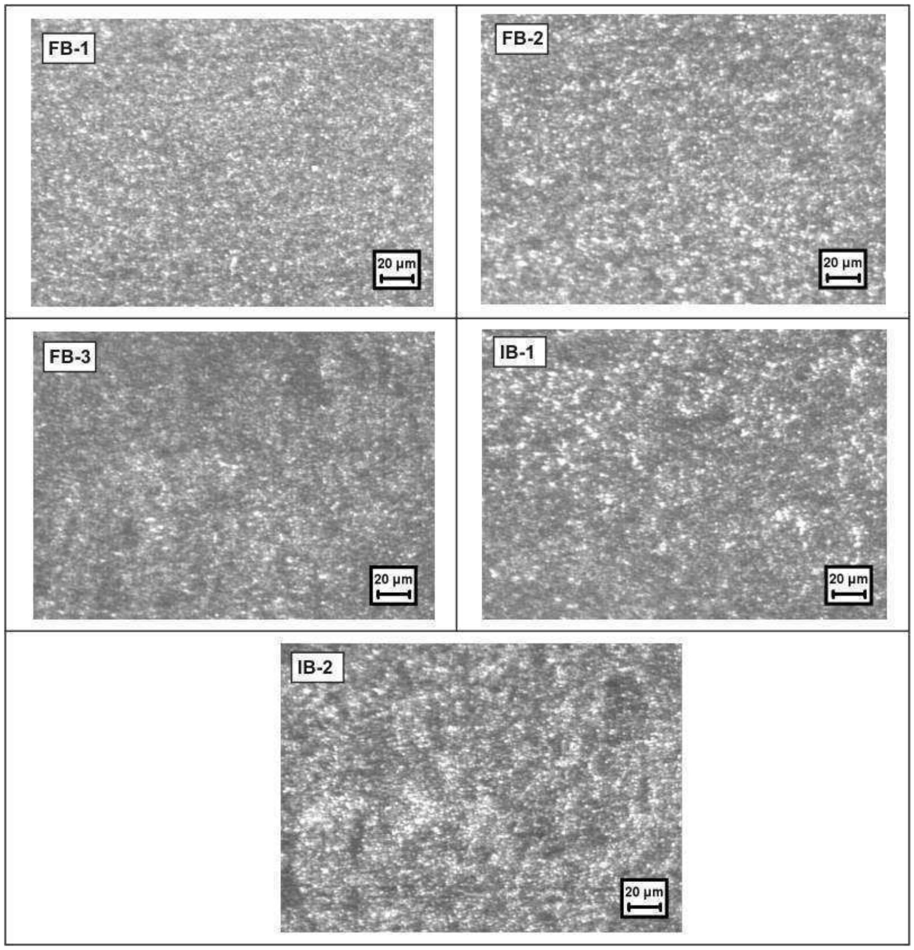

Fig. 5.7. Microstructure of different hooks.

Among the five types of hooks studied, there was no significant variation in the dimensional characteristics and weight. However, the mechanical strength properties showed a high degree of variation. This variability in the unbending force of the hooks could be due to the different material compositions and manufacturing process involved to produce different brands of hooks, which are generally specific for each manufacturer.

It was found that the unbending test method employed to analyse the mechanical strength of fishing hook in this study is in agreement with the actual performance by the fishing hooks in the field. The fishing hooks were classified as 'excellent', 'good' and 'poor' with regards to their mechanical strength based on the feed back collected from fishermen who are using these hooks. According to this, brands FB-1 & IB-1 were excellent, brands FB-2 & FB-3 were good and brand IB-2 was poor in their mechanical performance in the field. This is in agreement with the unbending test results with exception of FB-2 which showed poor mechanical strength in unbending test. Hence, it can be concluded that this test could be effectively used to evaluate mechanical strength of fishing hooks.

Mechanical strength of a fishing hook bend is very critical for successful fishing. Despite that only a few researchers have studied on the mechanical strength of fishing hooks. Varghese *et al.* (1997) carried out unbending test of fishing hooks by recording the load required for deformation of the hook bend. The result of the present study is in agreement with their study for the imported brand FB-2 (hook No. 7) which is represented in both the studies. According to their study, the only limitation of indigenous hooks was that they were prone to deformation under load. The indigenous fishing hooks were fragile and could be easily deformed under load when compared to imported brands of fishing hooks (Varghese *et al.*, 1997). But their conclusion was drawn solely based on the comparison of a single imported brand viz., FB-2 of the present study - with unbranded indigenous hook types collected from five firms. During that period, the selected imported brand was considered as the synonym for a standard hook. But the present study indicates that some indigenous brands are equally good in mechanical strength property compared to reputed foreign brands.

It is clear from the study that indigenous brands are comparable with imported brands of fishing hooks with respect to their physical and mechanical properties. These findings can be used in the selection of most suitable hook from the different brands available in the market as per the requirements.

5.3.3. Standardisation of hook numbering system

Hook numbering system is highly varied among different hook manufacturers and designating a hook merely by a relative ranking number (hook number) is felt inappropriate by many workers (Goldstein, 2000; Herd, 2004; Beverly, 2006; Colina, 2008). In this context an effort was made to standardize the hook numbering system used for different types of hooks.

In order to formulate a systematic hook numbering system, the different properties of fishing hooks were analysed in relation to their conventional hook numbers. It was found that there is a highly significant correlation (P=0.01) between hook size and gape width of hooks. Since gape width is an important factor influencing size selectivity, a new hook numbering system based on the gape size would be more useful and effective in fishing hook selection. Regression analysis and subsequent curve fitting was used to find out the interrelation between hook numbering and gape width (Fig. 5.8.). It was found that the hook number and gape width are inter related by an exponential equation $\mathbf{y = 33.37e^{-0.1045x}}$**,** where ‘y’ is the gape width for a given hook number (x).

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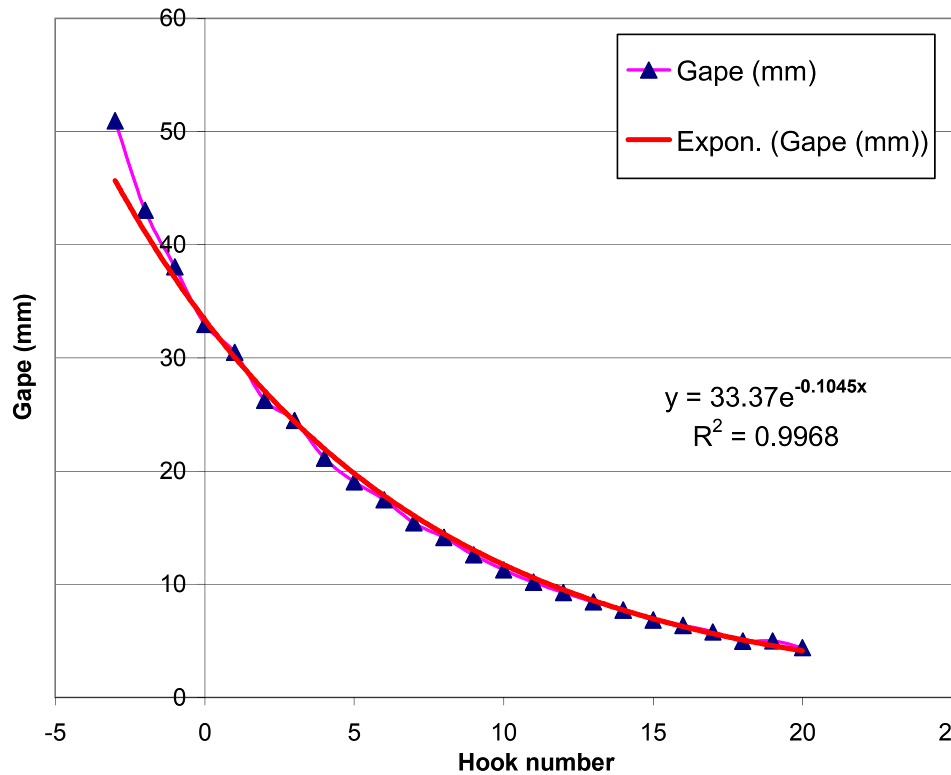

Fig. 5.8.   Correlation of hook number and gape width.

Similarly, the relationship of hook number with weight (Fig. 5.9.), diameter (Fig. 5.10.), total length (Fig. 5.11.), bite (Fig. 5.12.) and unbending load (Fig. 5.13.) of the hooks was also worked out. The corresponding equation and the R^2 of the equation is given in respective figures.

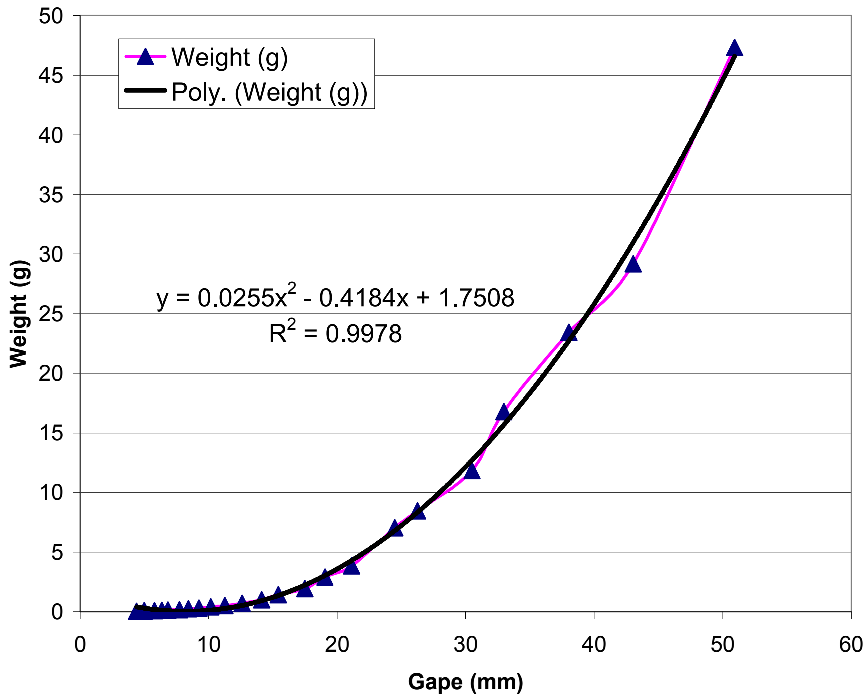

Fig. 5.9. Correlation of gape width and weight of hook.

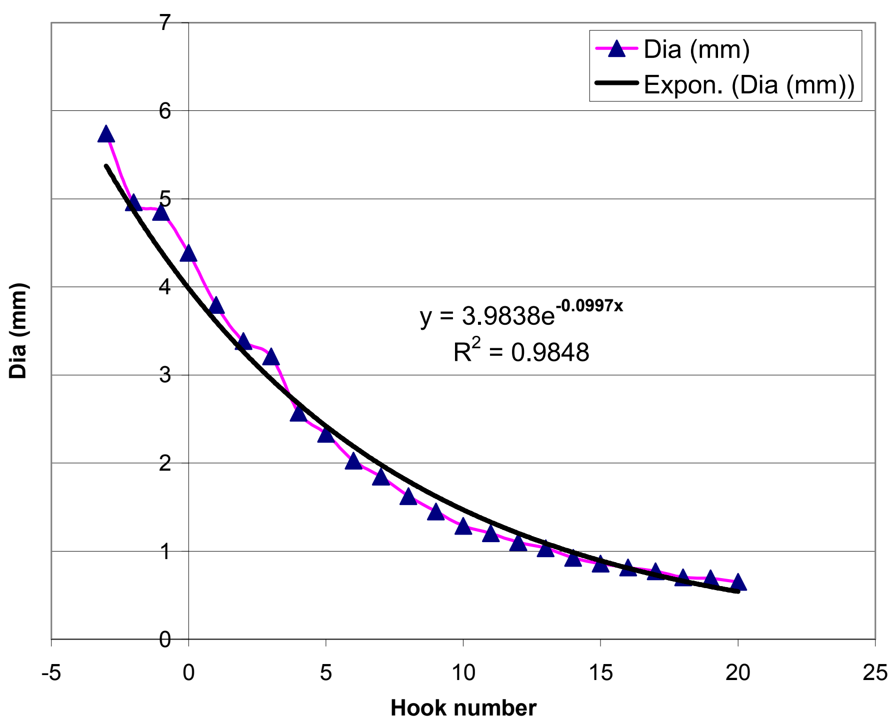

Fig. 5.10. Correlation of hook number and hook diameter.

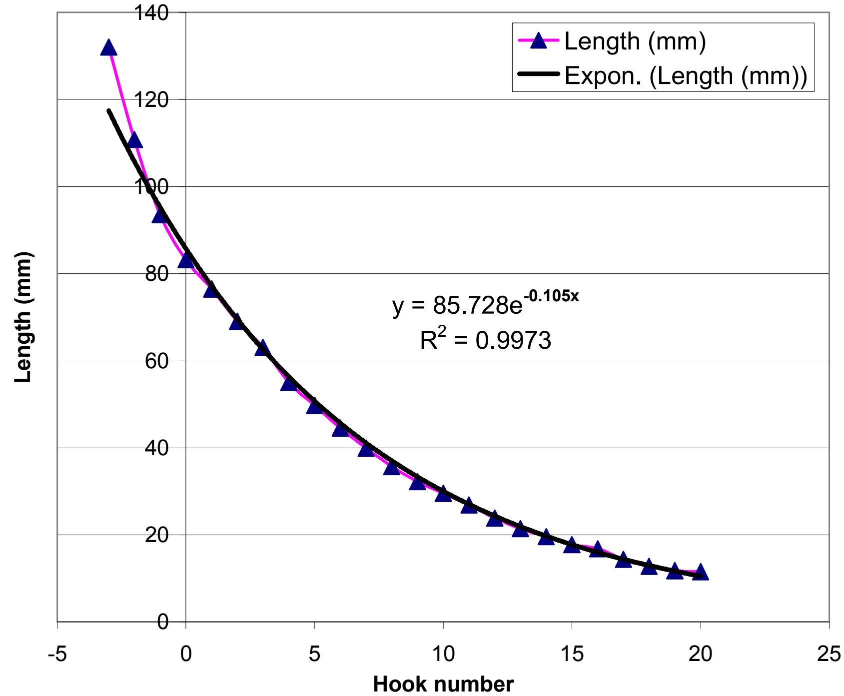

Fig. 5.11. Correlation of hook number and total length.

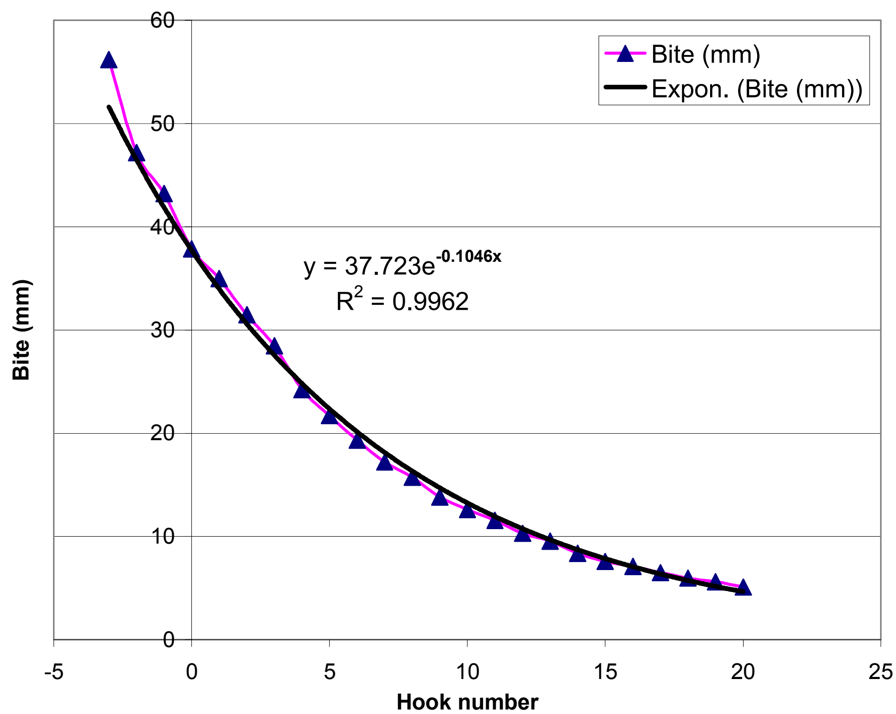

Fig. 5.12. Correlation of hook number and bite.

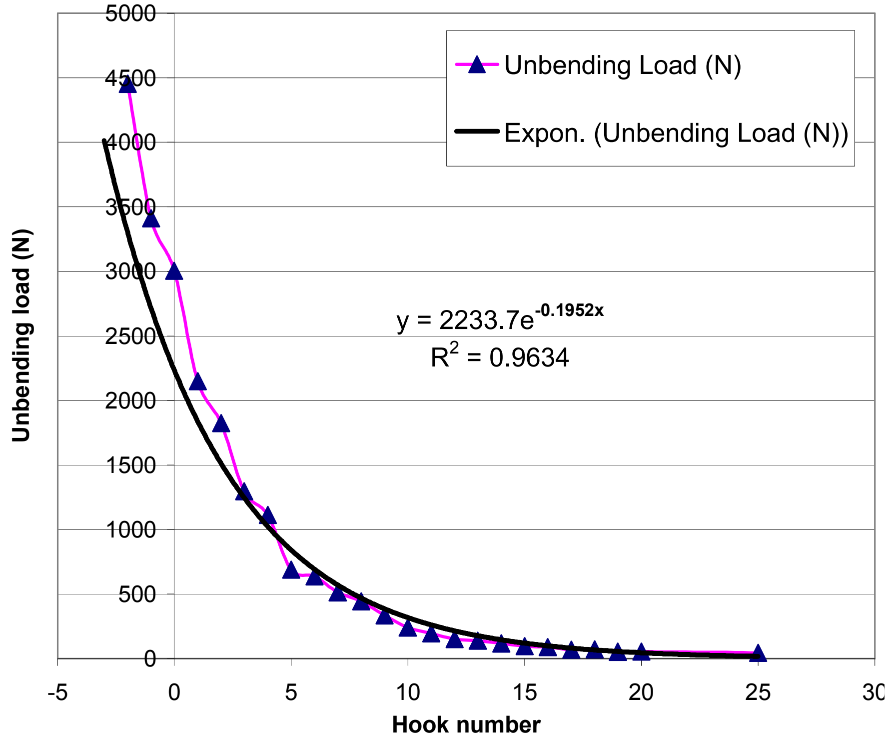

Fig. 5.13. Correlation of hook number and unbending load.

Based on the derived relationship of the hook number with different properties of hooks, properties of all the sizes of hooks – including that of the missing hook sizes in the marine numbering system was generated through extrapolation. These formulated specifications were verified with the observed properties of hooks studied. The unified standard specifications viz. gape, hook wire diameter, length of the hook, bite length, weight and unbending load worked out statistically based on the properties of samples of the hooks studied are given in Table 5.7.

In this new system, like in the marine numbering system, the finest/smallest hook is numbered 32 and it goes up numerically backwards to size 2,1 and then ‘0’. So here in this new system the transition hook number 1/0 in the conventional marine numbering system is designated as ‘0’ number hook for continuity and ease of analysis. Larger hooks above ‘0’ number hooks were given negative denominations which goes on decreasing as the size of hook increases (-1, -2, -3, ………. -19). This feature maintains the ability to incorporate still larger or smaller sizes of hooks in the system if need arises, as in the case of marine numbering system. In this study only the specification for hook sizes ranging from 32 to -19 (20/0 – in marine numbering) was worked out, but specifications for any size of hook can be formulated using this system. This generic specification can be used for unification of hook numbering system for all types of hooks with minor customizations if needed.

Table 5.7. Formulated standard specifications for fishing hooks.

Hook #	Gape (mm)	Dia (mm)	Length (mm)	Bite (mm)	Weight (g)	Unbending Load (N)
-19	243.02	26.48	630.29	275.25	4458.48	91145.71
-18	218.91	23.97	567.47	247.91	3296.66	74982.85
-17	197.19	21.70	510.90	223.29	2437.59	61686.15
-16	177.62	19.64	459.98	201.11	1802.38	50747.35
-15	160.00	17.77	414.13	181.14	1332.70	41748.33
-14	144.12	16.09	372.85	163.15	985.42	34345.10
-13	129.82	14.56	335.69	146.95	728.63	28254.69
-12	116.94	13.18	302.23	132.35	538.76	23244.29
-11	105.34	11.93	272.10	119.21	398.36	19122.38
-10	94.88	10.80	244.98	107.37	294.55	15731.41
-9	85.47	9.77	220.56	96.71	217.80	12941.76
-8	76.99	8.84	198.58	87.10	161.04	10646.80
-7	69.35	8.01	178.78	78.45	119.08	8758.80
-6	62.47	7.25	160.96	70.66	88.05	7205.61
-5	56.27	6.56	144.92	63.64	65.10	5927.84
-4	50.69	5.94	130.47	57.32	48.14	4876.65
-3	45.66	5.37	117.47	51.63	35.59	4011.88

-2	41.13	4.86	105.76	46.50	26.32	3300.45
-1	37.05	4.40	95.22	41.88	19.46	2715.18
0	**33.37**	**3.98**	**85.73**	**37.72**	**14.39**	**2233.70**
1	30.06	3.61	77.18	33.98	10.64	1837.60
2	27.08	3.26	69.49	30.60	7.87	1511.74
3	24.39	2.95	62.56	27.56	5.82	1243.66
4	21.97	2.67	56.33	24.83	4.30	1023.12
5	19.79	2.42	50.71	22.36	3.18	841.69
6	17.83	2.19	45.66	20.14	2.35	692.44
7	16.06	1.98	41.11	18.14	1.74	569.65
8	14.46	1.79	37.01	16.34	1.29	468.63
9	13.03	1.62	33.32	14.72	0.95	385.53
10	11.74	1.47	30.00	13.25	0.70	317.16
11	10.57	1.33	27.01	11.94	0.52	260.92
12	9.52	1.20	24.32	10.75	0.38	214.65
13	8.58	1.09	21.89	9.68	0.28	176.59
14	7.73	0.99	19.71	8.72	0.21	145.27
15	6.96	0.89	17.75	7.86	0.16	119.51
16	6.27	0.81	15.98	7.08	0.11	98.32
17	5.65	0.73	14.38	6.37	0.08	80.88
18	5.09	0.66	12.95	5.74	0.06	66.54
19	4.58	0.60	11.66	5.17	0.05	54.74
20	4.13	0.54	10.50	4.66	0.03	45.03
21	3.72	0.49	9.45	4.19	0.03	37.05
22	3.35	0.44	8.51	3.78	0.02	30.48
23	3.02	0.40	7.66	3.40	0.01	25.07
24	2.72	0.36	6.90	3.06	0.01	20.63
25	2.45	0.33	6.21	2.76	0.01	16.97
26	2.20	0.30	5.59	2.49	0.01	13.96
27	1.99	0.27	5.03	2.24	0.01	11.48
28	1.79	0.24	4.53	2.02	0.01	9.45

29	1.61	0.22	4.08	1.82	0.01	7.77
30	1.45	0.20	3.67	1.64	0.01	6.39
31	1.31	0.18	3.31	1.47	0.01	5.26
32	1.18	0.16	2.98	1.33	0.01	4.33

There is no widely accepted standard for the hook numbering system followed for the fishing hooks. Although attempts have been made to set a standard by measuring the hook length in fractions of an inch, the system has never been successful because it merely represents the length of the shank (Baranov, 1976). A hook is really three-dimensional and the gape can vary greatly from one pattern to the other. So a new system which can take into account all these special characteristics of fishing hooks would serve as a better standard which can be easily followed by all.

World over hooks are commonly designated by the marine numbering system and it is the most popular numbering system practiced by leading hook manufacturers. The major draw back of this system is that there is no uniformity in the numbering convention between hook types and also between different manufacturers. Since it is a relative ranking system, different manufacturers designate/number their hooks without any logical basis. So the actual hook size of different hook manufacturers may vary drastically, even though they are having same hook number. Moreover, designating a hook with just a number does not provide sufficient information on the peculiarities of a particular hook. With all these issues in view a new system of designating hooks – incorporating the basic hook properties – was developed. This system of hook numbering is basically a modification of the marine numbering system. The fishermen are very familiar with the marine numbering system so it has been taken as the back bone for the development of this new system. Specifying hooks based on the gape width as in the Indian Standard IS: 9860 (Part I) –

1981 was also incorporated in this new system. So the new proposed system is a hybrid between the marine numbering systems and the Indian Standard IS: 9860 (Part I) – 1981.

The proposed new system incorporates the most important attributes required for selection of a fishing hook such as type of bent, gape width and diameter of hook wire along with the hook number. This new proposed system is shown in Fig. 5.14. In the new system a hook designation is composed of four distinct parts separated by comas. The first part is the hook size. It can start from the smallest hook size 32 and goes on decreasing as the hook size increases up to size 1 and '0'. Hooks larger than the transition hook number '0' is given negative denominations and here also the number decreases as the hook size increases up to -19. The second part of the hook designation indicates the type of hook bent. Capital letter 'R' is used to denote a round bent hook, 'K' is used to denote a Kirby bent hook, 'L' is used to denote a Limerick hook, 'C' is used to indicate a Circle hook and 'T' is used to denote a tuna hook (Table 5.8.). The 3rd part in the hook number indicates the gape width in mm. The gape width in mm is indicated immediately after the letter 'G'. Finally in the fourth part the hook wire diameter in mm is indicated immediately after the symbol '∅' (Fig. 5.14.). For example a number 2/0 round bent hook (Marine numbering) having a gape width of 38mm and wire diameter of 4.85mm can be designated as **# -1, R, G38, ∅4.85**.

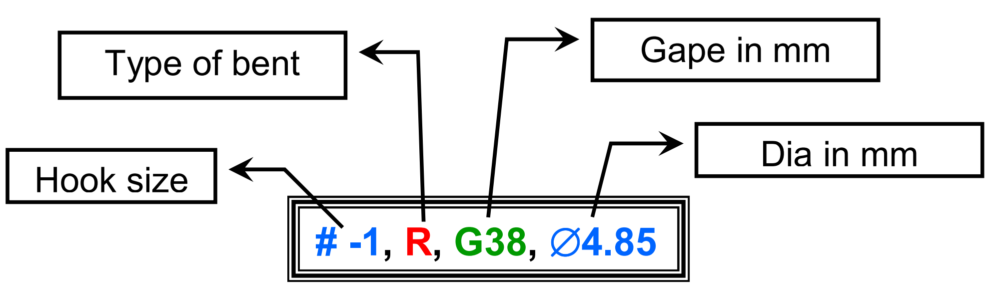

Fig. 5.14. Proposed hook numbering system

Table 5.8. Comparison of marine numbering system and the new numbering system.

Marine hook number	Proposed new system
2/0 (Round bent)	**# -1, R, G38.00, ∅4.85**
1/0 (Kirby bent)	**# 0, K, G33.00, ∅3.98**
1 (Limerick bent)	**# 12, L, G9.25, ∅1.20**
10/0 (Circle hook)	**# 5, C, G19.00, ∅2.35**
2 (Tuna hook)	**# 4, T, G20.00, ∅4.95**

This method of hook designation will enable the users to easily distinguish between different hook types and sizes. Following a unified numbering system will also allow direct comparison of different properties of fishing hooks. Other details like total length of hook, bite length, degree of offset, type of coating (Tin, Nickel, 'Blued' etc.), unbending resistance, wire material (Carbon steel, Stainless steel etc.), corrosion resistance etc. can also be incorporated. However, incorporation of more information in the hook numbering system may make it more complicated. This proposed system of hook numbering may be adopted as a unified standard by the industry after reaching a consensus among different manufacturers.

5.4. Conclusions

Physical and mechanical properties of all the 282 denominations of fishing hooks collected – coming under 7 imported brands, 7 Indian brands and 4 unbranded indigenous hooks - were studied, analysed and catalogued. No significant variation was observed among different types of hooks with respect to dimensional characteristics such as total length, hook wire diameter, gape and bite. However, considerable variability was noticed in their resistance towards unbending viz., deformation equal to bite length. It was found that hook number, size and properties of round bent and Kirby hooks are directly comparable whereas the hook number and properties of Limerick, Circle and tuna hooks were totally different from that of round bent hooks with the same number. There was a highly positive correlation between the hook number and the gape width of hooks. Similarly, there was positive correlation between the weight and the unbending force of the hook. The wire diameter of hook and the unbending force was also positively correlated. Since unbending test results were in conformance with the mechanical strength performance observed in the field, unbending test could be used for the selection of most suitable fishing hook from different types of hooks as per the strength requirements. A data base on the physical and mechanical properties was made as part of this study.

From the comparative study of indigenous and imported hooks, it was found that indigenous hook brand IB-1 is at par with imported brands in unbending strength. Since brand IB-1 has good mechanical strength, it could be substituted for the costly imported brands. It is clear from the study that indigenous brands are comparable with imported brands of fishing hooks with respect to their physical and mechanical properties.

Since there is no comprehensive and widely accepted specifications for fishing hooks, a new standard specification for fishing hooks viz., hook number, gape, hook wire diameter, length of the hook, bite length, weight and unbending load was developed. Also a new hook numbering system was developed as part of this study, giving importance to gape width and other properties of hook. All these would help in easy identification and direct comparison of different fishing hooks and in the selection of suitable hook.

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Chapter - 6

CHEMICAL COMPOSITION

6.1. Introduction

Fishing hooks are subjected to forces (loads) of varying magnitude when used for fishing and the mechanical strength of the hook is an important factor for successful fishing. It is more critical while fishing for fast moving large fishes like tuna and sharks. These fishes transfer high amounts of kinetic energy to the hook while hooking and this could lead to hook failure, which results in loss of catch.

Fishing hooks have been in use from time immemorial (Anon, 2004b). Copper (Cu) and bronze fishing hooks succeeded hooks made of wood, bones and sea shells used in ancient days (Fátima *et al.*, 2004; Helsinki, 1970). The present day fishing hooks are made from high carbon steel wire (Anon, 2002; Baranov, 1976). Studies indicate that the mechanical strength of steel depends on microstructure, which in turn is determined by their carbon content (Klueh, 1974). Thus the chemical composition of fishing hooks has a decisive role in determining the mechanical strength of the hooks. Further, it has been established by many researchers that differences in the core material of hooks and differences in the manufacturing process could lead to variations in their mechanical properties (Anon, 2002; Kitano *et al.*, 1990). The effectiveness of the heat treatment given to the hook during the manufacturing process is also dependent on the chemical composition of the core material.

Ko and Kim (1981) tested six types of fishing hooks for breaking and unbending due to plastic deformation of the material using a dynamometer. They also studied the dynamic forces acting on the hook during hooking and hauling. Varghese *et al.* (1997) studied the physical properties as well as corrosion resistance of fishing hooks. They carried out the unbending test of the hooks by recording the load required for deformation of the hook bend. Edappazham *et al*. (2008) studied the mechanical strength of hooks in relation to diameter and weight. The mechanical strength depended on material composition and heat treatment given during manufacturing process (Edappazham *et al*., 2008).

The aim of the present study was to analyse the effect of the chemical composition of the fishing hooks on their mechanical strength in terms of the unbending resistance of the hooks' bend. In addition to Carbon (C), the influence of various other chemical constituents such as Nickel (Ni), Manganese (Mn), Copper (Cu), Chromium (Cr) and Lead (Pb) on the mechanical strength in terms of unbending resistance of the hook bend is discussed.

6.2. Materials and Methods

Large sized number 3/0 round bent fishing hooks commonly used for catching, fast moving large pelagic fishes such as tuna and shark were selected. The selected hook types comprised of two branded hooks coded as B-1, B-2 and two unbranded indigenous hooks, coded as U-1, U-2. The physical dimensions of the hooks such as total length, bite length, gape and wire diameter were measured as per Indian Standard: 9860 (Part I) -1981.

6.2.1. Determination of chemical composition of the hooks

Composition of Carbon (C), Nickel (Ni), Manganese (Mn), Copper (Cu), Chromium (Cr) and Lead (Pb) content in the core material of the hooks were analysed. Chemical composition of core material of the hooks except the carbon content were analysed as per ASTM E 415 - 99 (2005). The carbon content was analysed by the combustion gravimetrical method as per ASTM E 352 - 93 (2000).

The coating on the hook was first stripped off using Con. HCl. The stripped hooks were washed in Millipore water and were dried and cut in to small piece of about 0.5 g in weight. The cut material was dissolved in minimum quantity of HCl and the analysis was carried out by Optima 2000 DV ICP-OES (Inductively Coupled Plasma Optical Emission Spectrometer). The plasma flame temperature was 1500 K (Kelvin) and the scan time was 3 seconds.

Standard reference materials (Sigma Standard Solution) and blank replicates were also run through the analysis protocols with minimal variation (coefficient of variation <7%) among samples. Metal recoveries for the standard reference materials were within their 95% confidence levels. All analyses were performed using clean, deionsed Millipore water (Milli Q; 0.22 µm) rinsed, dried glass wares and properly cleaned instruments as applicable. From the emission readings of the standard solution and that of the samples, the percentage of different elements in the sample was determined.

6.2.2. Determination of mechanical strength

To analyse the inter-relation between chemical composition and mechanical strength of the fishing hooks, unbending test of hooks was carried out as detailed in Chapter 5. Based on this data the correlation between the mechanical strength and the chemical composition was worked out.

6.2.3. Statistical analysis

The results were statistically analysed in order to find out the correlation between the unbending resistance and the chemical composition. Pearson's Co-efficient of Correlation was worked out to find out the relationship between each chemical constituent and unbending resistance.

6.3. Results and Discussion

6.3.1. Unbending resistance

The physical and mechanical properties of the fishing hooks studied is given in Table 6.1. The four types of hooks tested showed no significant difference in their physical properties. The diameter of the four types of hooks showed very low variation with a standard deviation as low as 0.01. However, significant variation was noticed in their unbending resistance ($P<0.05$). This was found to be mainly due to the variations in the Carbon (C) content of the core material and also could be due to the differences in the heat treatment given to the hooks during their manufacture (Edappazham et al., 2008).

Table 6.1. Physical and mechanical properties of fishing hooks

	B-1	B-2	U-1	U-2
Total Length (mm)	104.20 ± 0.92	114.70 ± 0.48	104.80 ± 0.42	119.60 ± 1.43
Diameter (mm)	4.86 ± 0.01	4.96 ± 0.01	5.03 ± 0.01	4.99 ± 0.02
Gape (mm)	45.20 ± 0.63	46.80 ± 0.42	36.40 ± 0.52	43.70 ± 0.67
Bite (mm)	47.40 ± 0.97	50.70 ± 0.67	42.70 ± 0.48	48.00 ± 1.15
Weight (g)	26.733 ± 0.18	29.444 ± 0.24	26.684 ± 0.21	33.836 ± 0.36
Unbending load (kN)	3.611 ± 1.14	3.680 ± 1.41	3.529 ± 1.89	2.828 ± 1.52

6.3.2. Chemical composition

The chemical compositions of core material of the fishing hooks studied is given in Table 6.2. There was no significant difference in the chemical composition of the core material of different hooks. However, nickel, copper, chromium and lead showed variations among different samples.

Table 6.2. Chemical composition of fishing hooks (wt. %)

	B-1	B-2	U-1	U-2
Carbon (C)	0.760 ± 0.084	0.760 ± 0.101	0.760 ± 0.252	0.750 ± 0.176
Nickel (Ni)	0.036 ± 0.011	0.006 ± 0.012	0.011 ± 0.004	0.031 ± 0.001
Manganese (Mn)	0.619 ± 0.032	0.649 ± 0.015	0.638 ± 0.012	0.615 ± 0.028
Copper	0.083 ±	0.017 ±	0.013 ±	0.082 ±

(Cu)	0.016	0.007	0.004	0.031
Chromium (Cr)	0.020 ± 0.001	0.009 ± 0.005	0.055 ± 0.016	0.036 ± 0.004
Lead (Pb)	0.004 ± 0.003	0.003 ± 0.002	0.009 ± 0.001	0.011 ± 0.002

6.3.2.1. Carbon content and unbending resistance

In the present study, the carbon (C) content varied from 0.750 to 0.760% by weight among the samples (Table 6.2.). There is a significantly high positive correlation between the carbon content and the unbending resistance, r= 0.99, P<0.05 (Fig. 6.2.). Since high carbon steel wire is used in the manufacture of the hook, the carbon content plays a very decisive role in the mechanical properties of fishing hooks (Anon, 2002; Baranov, 1976).

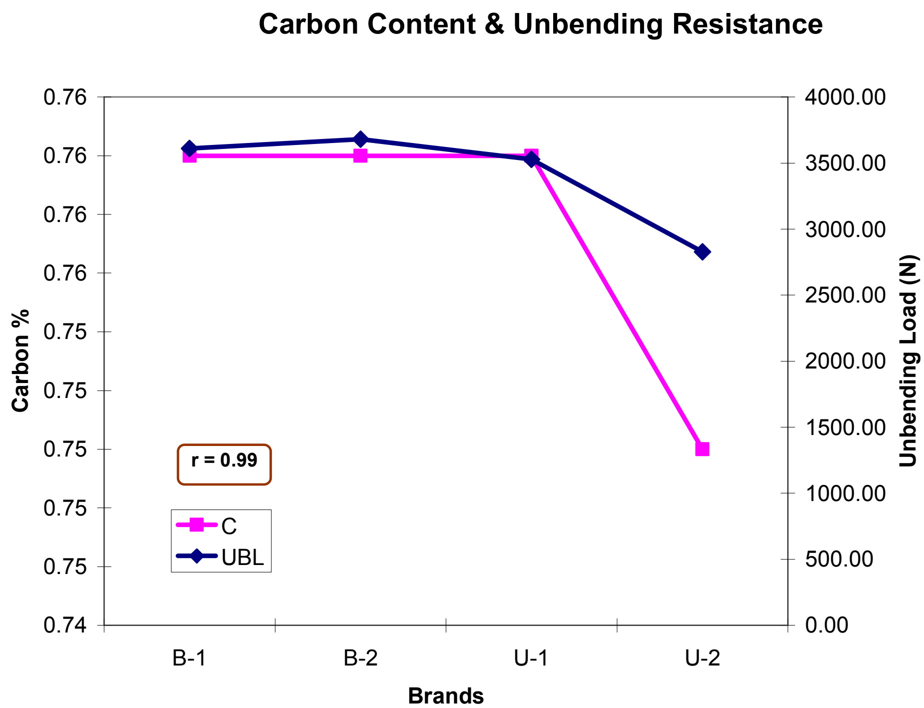

Fig. 6.2. Correlation between unbending resistance and carbon (C) content of hook.

6.3.2.2. Nickel content and unbending resistance

Similarly, the correlation between the Nickel content and the unbending resistance was also worked out. The Nickel content was negatively correlated with the unbending resistance of hooks, r= -0.46, P<0.05 (Fig. 6.3.).

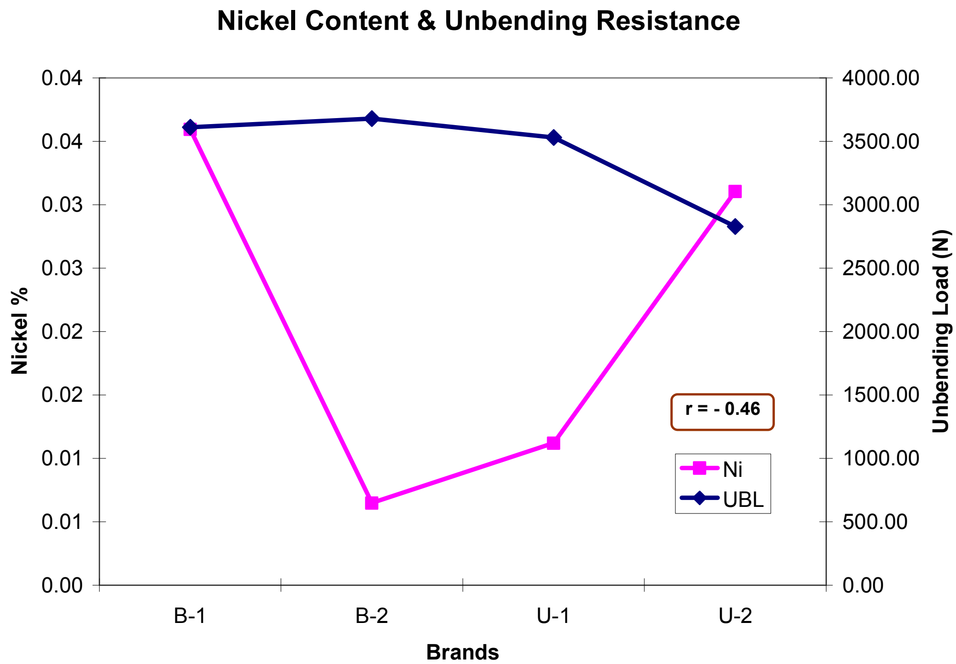

Fig. 6.3. Correlation between unbending resistance and nickel (Ni) content of hook

6.3.2.3. Manganese content and unbending resistance

In the case of manganese (Mn) content, there was positive correlation (r= 0.65, P<0.05) between the unbending resistance and manganese content of the hooks (Fig. 6.4.).

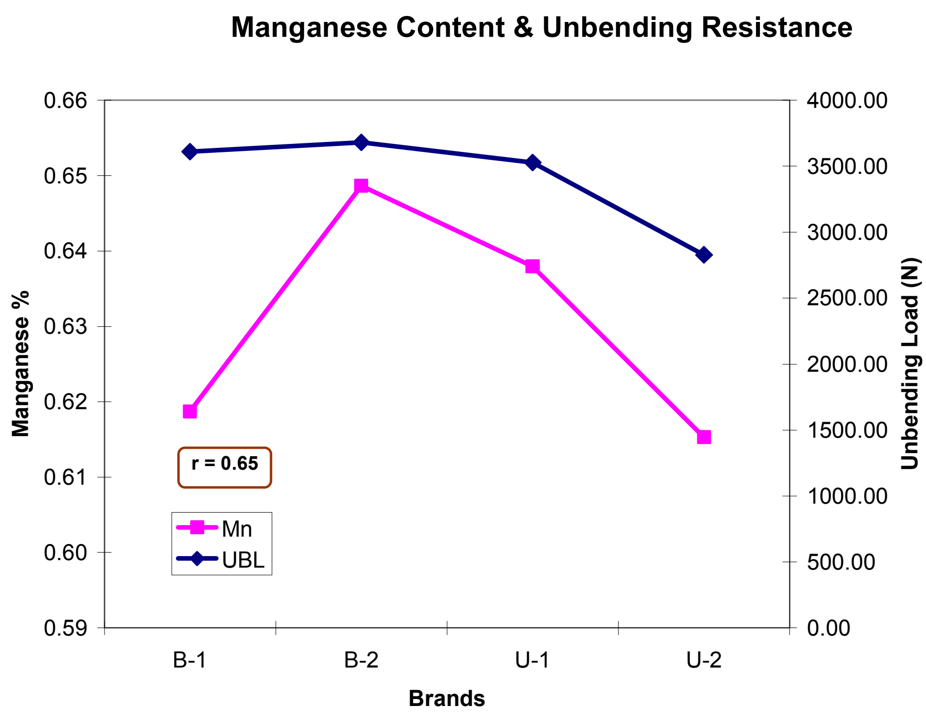

Fig. 6.4. Correlation between unbending resistance and manganese (Mn) content of hook

6.3.2.4. Copper content and unbending resistance

The copper (Cu) content of hooks varied from 0.01 to 0.08 wt. % among the four samples. There was negative correlation between the unbending resistance and copper content, r= -0.55, $P<0.05$ (Fig. 6.5.).

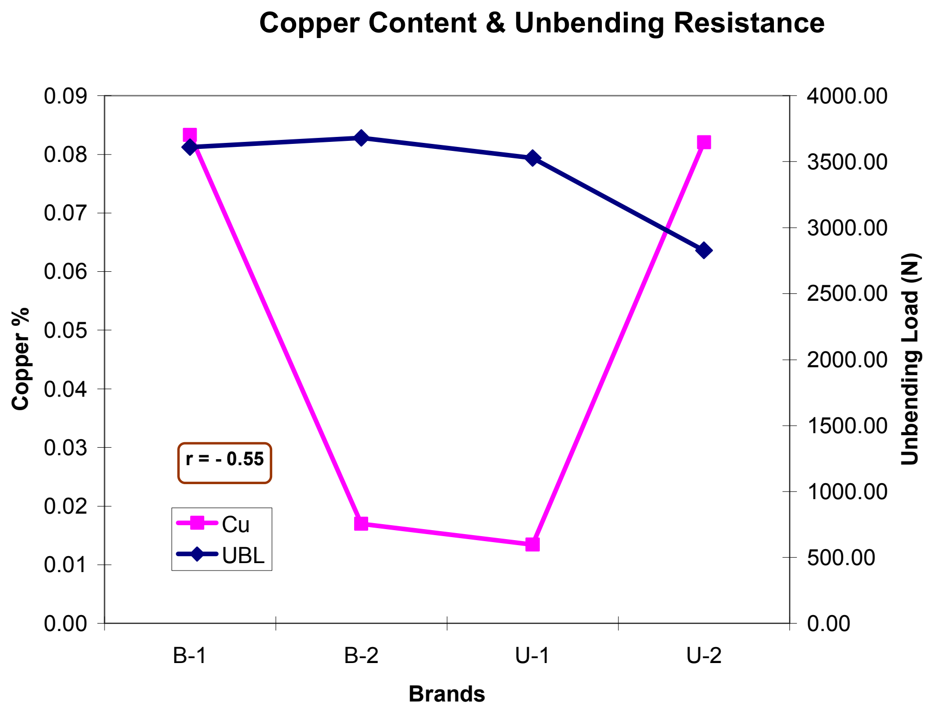

Fig. 6.5. Correlation between unbending resistance and copper (Cu) content of hook

6.3.2.5. Chromium content and unbending resistance

The chromium (Cr) content was also negatively correlated with the unbending resistance of fishing hooks, r= -0.34, P<0.05 (Fig. 6.6.).

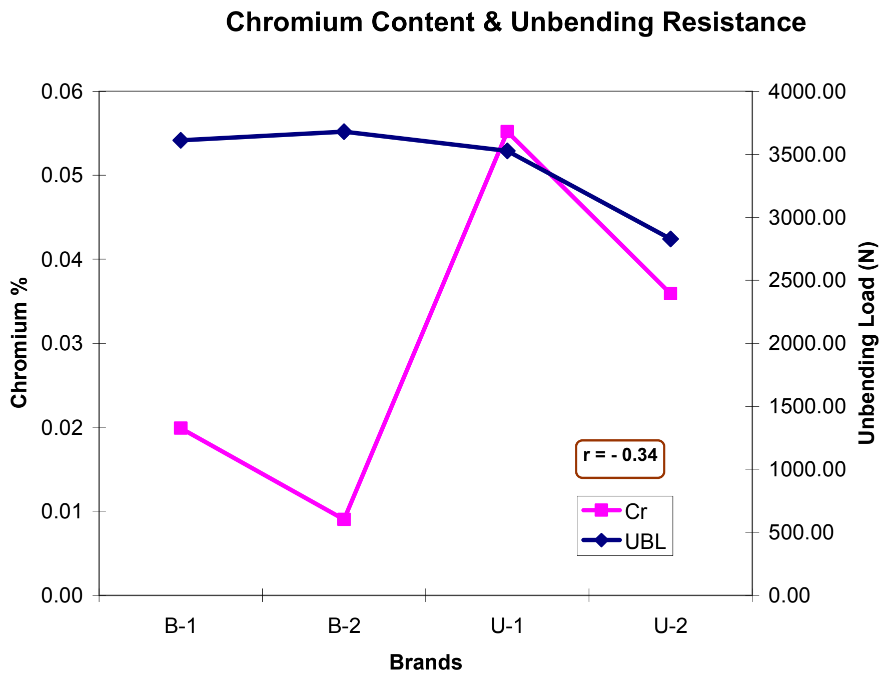

Fig. 6.6. Correlation between unbending resistance and chromium (Cr) content of hook

6.3.2.6. Lead content and unbending resistance

The wt. % of lead (Pb) was found very low when compared to the other constituents studied as it varied from 0.003 to 0.011 wt. % among the four samples (Table 6.2.). There was significantly high negative correlation between the unbending resistance and lead (Pb) content, r= -0.78, P<0.05 (Fig. 6.7.).

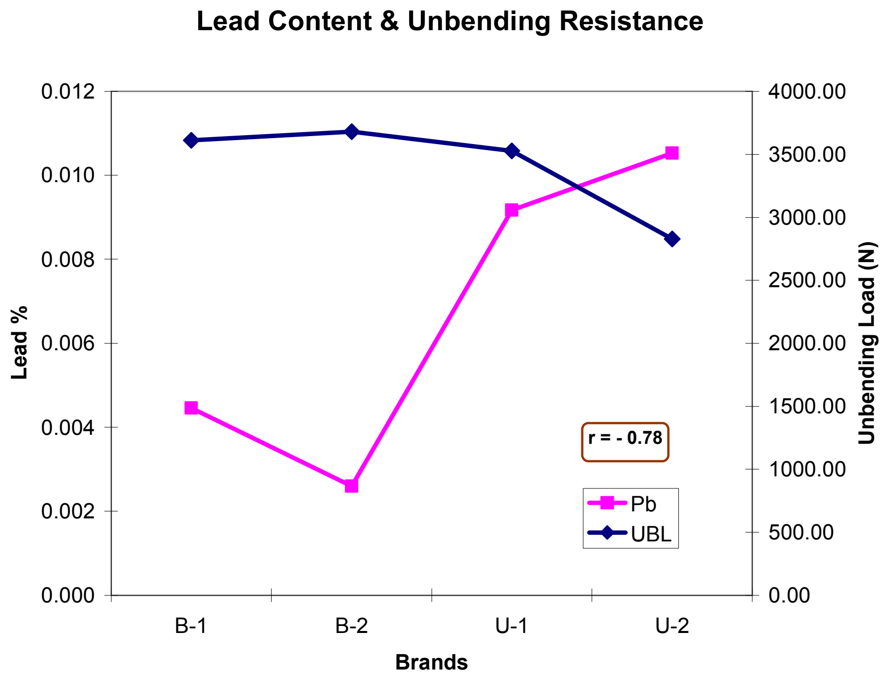

Fig. 6.7. Correlation between unbending resistance and lead (Pb) content of hook

Though the chemical composition of the four samples were approximately same, lead (Pb) content was high in unbranded indigenous samples U-1 and U-2 (Table 6.2.). This difference in Pb content might be due to the type of ore used in the smelting process. It could also be due to intentional addition of lead which lowers the melting point resulting in a more malleable alloy as this was a common practice during the Bronze Age (Fátima *et al.*, 2004). As the unbranded indigenous hooks are made by small-scale artisanal blacksmiths, this seems to be the probable reason for high lead content in the unbranded indigenous hook samples U-1 and U-2.

The carbon content in steel indeed has a major role in deciding the mechanical properties of steels. Tensile tests conducted by Klueh, (1974) on steel at different temperatures indicated that strength depended on microstructure, which in turn was determined by the carbon content of steels. Hooks with high mechanical strength had a uniform fine grain-sized microstructure when compared to hooks with poor mechanical strength (Edappazham *et al.*, 2008). High tensile-strength steels could be successfully produced by optimizing the chemical composition and heat treatment (Srivastava *et al.,* 2006). Presently, Indian hook manufactures are dependent on costly imported steel wire to make hooks (DST, 2001). The present study indicates that the indigenously produced hooks are equally good in their physical, chemical and mechanical properties with that of branded hooks. These properties could be further altered using appropriate methods to produce hooks with desired properties.

6.4. Conclusions

Chemical analysis of the core material of branded and unbranded hooks revealed that there was significant positive correlation between the carbon (C) content and the unbending resistance of the hook samples studied. The manganese (Mn) content was also found to be positively correlated to the unbending resistance. Nickel (Ni), copper (Cu), chromium (Cr) and lead (Pb) were negatively correlated to the unbending resistance. Significantly large amount of lead (Pb) was present in unbranded indigenous hook samples U-1 and U-2 compared to the branded hooks. It was found that indigenously produced hooks are comparable in their chemical and mechanical properties with that of imported fishing hooks.

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Chapter - 7

CORROSION RESISTANCE

7.1. Introduction

Limited service life of fishing hooks is a major problem faced by hook and line fishing industry. Corrosion is the most important factor, which affects the service life of fishing hooks. Corrosion is an oxidation reaction of metals in the presence of water or an electrolyte. For Iron (Fe) this process is known as rusting (Pi, 2004). Metal corrosion commonly occurs via electrochemical reactions at the interface between the metal and an electrolyte solution. Corrosion normally occurs at a rate determined by an equilibrium between opposing electrochemical reactions. The first is the anodic reaction, in which a metal is oxidized, releasing electrons into the metal. The other is the cathodic reaction, in which a solution species (often O2 or H^+) is reduced, removing electrons from the metal. When these two reactions are in equilibrium, the flow of electrons from each reaction is balanced, and no net electron flow (electrical current) occurs. The two reactions can take place on one metal or on two dissimilar metals (or metal sites) that are electrically connected.

The corrosion has a significant impact on the world economy. It affects almost all walks of life including infrastructure, transportation, utilities, production and manufacturing. The metal corrosion is a serious problem that costs severely on the economy of a country. It is estimated that about 4% of GDP of a developed country is lost due to corrosion, where the share of industry in GDP is in the range of 32 to 41%. The corrosion of iron costs the U.S. economy about $70 billion annually (Blaber, 2000). The loss due to corrosion in India is estimated to be 4% of GNP. This amounts to Rs. 24,000 crores for the year 1996-1997 (Palaniswamy, 2006).

Corrosion of metallic fishing hooks is a perpetual problem as they are operated in highly corrosive environment like the seawater which is considered as the most corrosive natural environment. Seawater is a complex mixture of inorganic salts (mainly sodium chloride), dissolved gases (mainly oxygen), suspended solids, organic matter and organisms (Todd, 1986). Seawater is corrosive mainly due to its salt content. Water in open sea contains about 3.4 % salt and excess of basic ions which raise the pH slightly in the alkaline range (pH 8.0). It therefore serves as a strong electrolyte and can cause excessive corrosion (Basu *et al.*, 1977). Lee *et al.* (2004) reported that Corrosion of 1020 carbon steel coupons in natural seawater over a 1-year period was more aggressive under strictly anaerobic stagnant conditions than under aerobic stagnant conditions. The corrosion rates were measured by weight loss and instantaneous corrosion rate (polarization resistance). In both aerobic and anaerobic exposures, corrosion was more aggressive on horizontally oriented coupons compared to vertically oriented samples.

Fishing hooks operated in water bodies especially in marine waters are prone to severe corrosion. This poses a serious problem for the fishermen. Excessive corrosion of fishing hooks will lead to significant reduction in their mechanical strength and this could ultimately result in hook failure and escapement of their valuable catch. Besides, the fishermen are required to 're-sharpen' or replace the hooks at regular intervals as the points loose their sharpness due to corrosion. This calls for a lot of human effort and loss of fishing days apart from the other costs involved such as depreciation (Kitano *et al.*, 1990).

Fishermen from ages have been devising various methods to prevent or minimize corrosion of their hooks. Baranov (1976) mentioned about coating the spears of 're-sharpened' hooks with solid lubricants like tar, grease and cerolin by fishermen to prevent corrosion. Modern hook manufacturers use special anticorrosive coating to tackle this problem. The performance of these coatings often varies from manufacturer to manufacturer. Although modern methods are available to prevent or to reduce the loss, costs are involved as in the case of application of special anticorrosive coatings for protection (Cottis, 1982). Cathodic protection of fishing hooks by application of aluminium sacrificial anodes as experimented by Kitano *et al.*, (1990) could lead to reduced fishing efficiency as the hook will get bulkier and makes it more perceivable to the fish.

Apart from the disadvantageous nature, the corrosion of fishing hooks has some useful aspects also, especially in the sport fishing where 'catch and release' practice is followed. In recreational angling, fast corroding fishing hooks would be favoured over corrosion resistant fishing hooks. Usually 'hard hooked'/ 'deep hooked' / gut-hooked (where it is very difficult to remove the hook without seriously injuring the fish) fishes are set free with the hook inside the body and the hook will get completely corroded in due course of time. A fast corroding hook will improve the survival rate of fishes in such cases. Releasing of gut-hooked fish with the lines cut with the hook inside the fish body significantly improved survival rates up to 85% (Butcher *et al.*, 2007).

As corrosion is an important factor determining the performance of any metallic articles and components, different evaluation methods are used in the industry for the assessment of corrosion resistance. Such corrosion tests can be carried out on production articles or on specially prepared flat panels (coupons). But it is always advisable to test actual production articles, both for quality checking and for evaluating the performance. The assessment of corrosion of actual production articles is more difficult than on flat panels because of the problem of accurate determination of surface area (Carter, 1982). Since corrosion is mostly a slow process, accelerated corrosion tests are used. The purpose of an accelerated corrosion test is to evaluate the corrosion performance of a product in the laboratory within a very short period. It is generally assessed by the corrosion resistance test using a salt spray chamber. The salt spray test is an accelerated corrosion test by which samples exposed to the same aggressive condition can be compared simultaneously thereby one has a means of ranking the relative corrosion resistance. The salt spray test is carried out in Salt Spray Chamber in accordance with the ASTM B-117 norms (ASTM B 117 - 03, 2003). Basically, the salt spray test procedure involves the spraying of a salt solution onto the samples being tested. This method is considered as the most suited method for evaluating general corrosion resistance (Basu *et al.*, 1977; Natishan *et al.*, 2000 and Papadopoulos *et al.*, 2007). For many years, the salt spray test has been used extensively by researchers for the evaluation of different coatings. García and Suay, (2006) reported that salt fog spray test and its variants are the most effective technique used in the prediction of the anticorrosive properties of organic coatings.

Corrosion resistance is an important criterion in the quality evaluation of the fishing hooks also. In fishing hooks the corrosion resistance may vary depending on the type of the material, the type and thickness of the coating, fishing conditions, water temperature and pH and type of bait. Currently, no standard method available specifically for the accelerated corrosion evaluation of fishing hooks. Therefore, suitable standard accelerated corrosion tests such as the salt spray (salt fog) test may be used to evaluate the corrosion performance of fishing hooks. It is also worth mentioning that the salt fog test can not be used for the accurate prediction of service life of the fishing hooks in field as different complex mechanisms are involved in the corrosion and its propagation in natural marine environment. The oxygen content has marked effect on corrosivity of seawater and where this is reduced, the seawater is less corrosive. Tests in solutions of salts approximating seawater composition can give misleading results, and it is now realized that living organisms have an influence on corrosion behaviour (Lee *et al.*, 2004). Thus a thin layer of marine growth can reduce corrosion on carbon steel. However, salt fog test is very commonly used in the industry and is best suited for evaluating the relative corrosion resistance of different samples in the laboratory.

Desirable protective coating or finish is provided to the fishing hook to minimize corrosion. Generally tinned, nickeled, ‘blued’, ‘Japanned black’, ‘red’ and ‘bronzed’ are the common finishes applied to the hooks. The protective effect of these coatings is not scientifically studied. Therefore, fishing hooks with the most common coatings viz., tinned and ‘blued’ were analysed to find out their corrosion resistance property.

Crevices/enclosed spaces formed can add to the rate of corrosion. In fishing hooks, fishing line, snood wire etc. are tied and this facilitates formation of crevices at the point of attachment. Kitano *et al.* (1990) studied the effect of attachment of monofilament on tuna long line fishhook. Snood wire is often used in shark lines to avoid biting off the hooks. The attachment of snood wire ie., a metallic structure to the fishing hook can lead to increased corrosion. However, no study has been reported so far on this aspect. Hence this aspect was also taken up in this study.

Cerium (Ce) is known to act as an effective corrosion inhibitor (Ashraf and Shibli, 2007; Yu *et al.* 2001; Bethencourt, *et al.*, 1998). Hence the effect of Cerium treatment of fishing hooks on their corrosion resistance was also studied. Fishermen generally apply different types of oils, such as lubricant oil and fish oil, on their hooks as means of protection. The protective effect of this method is not scientifically reviewed so far. Hence the effect of applying fish oil and lubricant oil was also evaluated as a part of this study.

Since salt spray (salt fog) test is considered as the most suitable method for the accelerated evaluation of corrosion resistance, this test was used for the evaluation of the corrosion resistance of fishing hooks. As hooks of different manufacturers and brands, both imported and indigenous, are to be evaluated they were simultaneously subjected to salt spray test. The results of the study are detailed in this chapter. The studies comprised (i) comparison of corrosion resistance of indigenous (branded and unbranded) hooks with imported fishing hooks, (ii) effect of different surface coatings on the corrosion resistance of fishing hooks, (iii) effect of snood wire on corrosion resistance of hooks, (iv) effect of Cerium (Ce) treatment on the corrosion resistance of hooks and (v) effect of oil treatment on the corrosion resistance of fishing hooks.

7.2. Materials and Methods

7.2.1. Comparison of corrosion resistance: Indian fishing hooks Vs imported hooks

7.2. 1.1. Specimen

Hook number 1, round bent ('J' style) shark fishing hook with tinned finish was selected for the study. Fishing hooks of most popular brand of imported, Indian and unbranded indigenous fishing hooks were taken for this study. Ten samples of each type (n=10) were used for each set. The physical dimensions of the hooks were measured following IS: 9860 (Part I) – 1981. Wire diameter measurement was taken on the round unforged shank portion (The long unbent portion of a hook) of the hook using a micrometer (Mitutoyo, d = 0.01mm).

Prior to salt spray exposure, the hook samples were degreased using acetone to remove any dirt and oil that may be present on the surface. After drying, the weight of the hooks was recorded using a high accuracy electronic balance (Sartorius BP211D, d = 0.01mg).

7.2.1.2. Salt spray analysis

The hooks were subjected to salt spray (salt fog) in a standard salt spray cabinet as per ASTM B117 standard (ASTM B 117 - 03, 2003). A photographic representation of the experimental set up is given in Fig. 7.1.

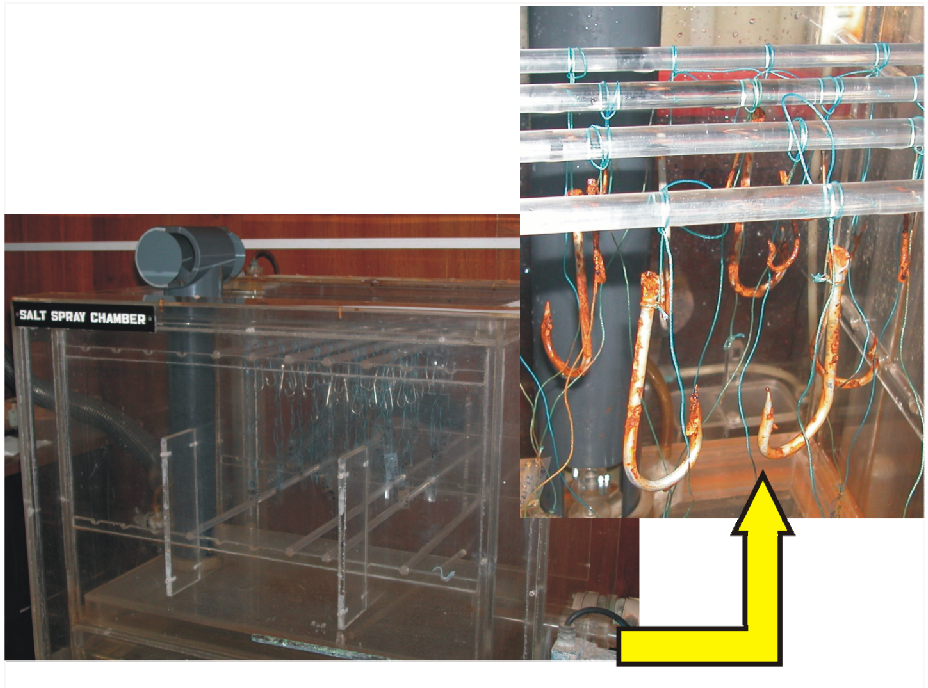


Fig. 7.1. Hooks in the salt spray chamber.

A standard salt spray cabinet of 0.90 m x 0.72 m x 0.72 m dimension was used. The salt solution was prepared by dissolving five parts by weight of sodium chloride (AR) into 95 parts of distilled water. The salinity, pH and temperature of the prepared solution were measured (pH tester 30, Eutech Instruments). The pH of the salt spray solution was maintained in the pH range of 6.5 to 7.2 at 35°C. The temperature inside the salt spray chamber was maintained at 35 ±1°C. The hooks were suspended inside the cabinet using thin plastic strings (Fig. 7.1.) and a uniform saturated salt spray was maintained throughout the test period. Sodium Chloride (NaCl) solution was sprayed as very fine mist over the samples.

The hooks were exposed to three hundred hours of salt spray. The exposure time was selected based on a preliminary study in which hooks were exposed up to 500 h of salt spray. The results from this study were statistically analysed and found 300 h as the optimum exposure period ($P \leq 0.01$). The hooks were visually observed for the extent of corrosion at every 100 hours. Ten hooks each were drawn after completion of every 100 h of exposure to find out the corresponding weight loss and corrosion rate.

The hooks thus drawn after completion of the specified exposure were washed with clean running water to remove any salt deposits from their surface. The corrosion product buildup on the hook surface was cleaned using Clarke's solution as per ASTM G1 by dipping in the Clarke's solution for about 25 minutes at room temperature (ASTM G1 - 03, 2003). Then they were rubbed with rubber pads to remove any attached corrosion products, cleaned in running water and dried. The hooks were weighed again to find out the weight lost during the test.

From the weight loss, the corrosion rate was calculated using the formula:

$$\text{Corrosion rate} = \frac{\mathbf{K} \times \mathbf{W}}{\mathbf{D} \times \mathbf{A} \times \mathbf{T}}$$

Where: **K** = A constant *

W = Weight loss in gram

D = Density in g/cm^3

A = Surface area in cm^2

D = Time in hours.

*The value for the constant '**K**' is 3.45 x 10^6 for corrosion rate calculation in terms of 'mils per year' (mpy).

The percent weight loss (**ω**) was calculated as per the following formula:

$$\omega = \frac{M_0 - M_c}{M_0} \times 100$$

Where: M_0 is the initial weight of the specimen and M_c is the weight of the corroded specimen, after cleaning.

7.2. 2. Effect of surface coatings on the corrosion resistance

7.2. 2. 1. Specimen

The two most common hook finishes namely the tinned (Quality No. 1100) and 'blued' (Quality No. 1000) finishes were used for this study. These sets were drawn from hook number 7, round bent flatted hooks of a Japanese hook manufacturer. The chemical composition of core material of the hooks is given in Table 7.1.

Table 7.1. Chemical composition of core material of hooks (wt. %).

	Tinned hook	**Blued hook**
Manganese (Mn)	0.32	0.41
Nickel (Ni)	0.05	0.04
Copper (Cu)	0.06	0.05
Chromium (Cr)	0.09	0.08
Carbon (C)	0.65	0.69

Ten samples (n=10) were used for each set. The physical dimensions of the hooks were measured as explained earlier in chapter -3. Just prior to salt spray exposure, the tinned hook samples were degreased using acetone to remove any dirt and oil that may be present on the surface. The 'blued' hook samples were simply cleaned in distilled water as using any type of organic solvents could damage the lacquer. After cleaning, the hooks were dried, and then the weight of the hooks was recorded.

7.2. 2. 2. Salt spray analysis

The tinned and 'blued' hooks were exposed to salt spray (salt fog) in a salt spray cabinet as per ASTM B117 as explained in section 7.2.1.2.

The surface characteristics of the specimens were examined by optical microscopy (OM) (Leica MZ16 A). The change in wire diameter after the salt spray exposure was also measured by calibrated optical microscope.

7.2. 3. Effect of snood wire on corrosion resistance

7.2. 3. 1. Materials used

Round bent flatted fishing hook of No. 7 size from a leading fishing hook manufacturer was used for this study. The physical dimensions of the hooks used for the study are given in Table 7.2.

Table 7.2. Physical dimensions of the hooks.

Hook Size	No. 7
Wire Diameter (mm)	1.82
Gape (mm)	15.90
Bite (mm)	17.50
Total Length (mm)	40.00
Weight (g)	1.398

7.2. 3. 2. Snood wire

Grade 304H, stainless steel wire of 0.20mm diameter was used for the snood wire. This wire was twisted into an eight stranded wire of 200mm length, exactly as practiced by the hook and line fishermen of Thoothoor in Tamilnadu (India). This was tied to the eye of the fishing hook (Fig. 7.2.).

Fig. 7.2. Snood wire tied to the eye of fishing hook (10x).

Two sets of samples, one with snood wire and another set without snood wire (Control) were prepared. These samples were then degreased using acetone and dried just before exposing them to salt spray.

7.2. 3. 3. Salt spray analysis

The hooks were subjected to salt spray as explained in section 7.2.1.2. After completion of the salt spray exposure, the hooks were cleaned and the weight loss and corresponding corrosion rates were calculated. The surface characteristics at the eye portion of the specimens were examined by optical microscopy (OM) (Leica MZ16 A).

7.2.4. Effect of Cerium (Ce) treatment on the corrosion resistance

7.2. 4.1. Materials used

Round bent flatted fishing hook of No. 7 size from a leading fishing hook manufacturer was used for this study. Two sets of samples, one treated with Cerium (Ce) and another set without such treatment (Control) were prepared. The physical dimensions of the hooks used are detailed in Table 7.2.

7.2.4.2. Treatment with Cerium (Ce)

The hook samples were cleaned and degreased with acetone and dried in a hot air oven. A 2000ppm Cerous Chloride ($CeCl_3$) solution was prepared with Millipore water and maintained at 50°C. About 1ml of 30 wt.% of Hydrogen Peroxide (H_2O_2) was added to this solution and the pH was adjusted to 5.4. The hooks were heated up to 200°C and immediately immersed in the prepared Cerium solution and were kept immersed for one hour. Then they were taken out and dried. After drying they were directly exposed to salt fog along with control.

7.2. 4.3. Salt spray analysis

Both Cerium treated and control hooks were exposed to 300h of salt fog in a standard salt spray chamber as per ASTM B 117 - 03 (2003) and the results were analysed as in section 7.2.1.2.

7.2.5. Effect of oil treatment on the corrosion resistance

7.2.5.1. Materials used

Round bent flatted fishing hook of No. 1 size from a leading fishing hook manufacturer was used for this study. The hooks were treated with common lubricant oil and fish oil (Sardine oil) to find out the effect of oil application on their corrosion resistance.

7.2.5.2. Treatment with oils

The hooks were cleaned and degreased with acetone. Then they were dried and their weights were recorded. From these hooks three sets composed of 10 hooks each (n=10) were prepared for the experiment. One set of hooks was treated with lubricant oil by smearing the oil over the hook surface. Similarly another set was prepared by smearing the hooks with fish oil. The third set was prepared without any treatment as control.

7.2.5.3. Salt spray analysis

The two sets of hooks treated with oils and the control hooks were exposed to 300h of salt fog in a standard salt spray chamber as per ASTM B 117 - 03 (2003) and the results were analysed as detailed in section 7.2.1.

7.2.6. Statistical analysis

All statistical analyses were performed using SPSS 12.0 (SPSS, Inc., Chicago, IL). Differences in the weight loss and corrosion resistance between the hooks were analysed using analysis of variance (ANOVA). The significance levels were tested at $P \leq 0.05$ level.

7.3. Results and Discussion

7.3.1. Comparison of corrosion resistance: Indian fishing hooks Vs imported hooks

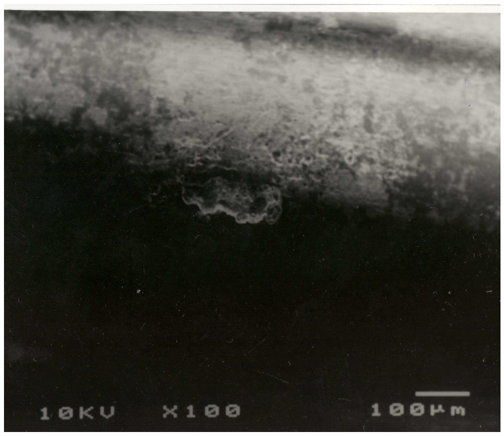
7.3.1.1. Visual evaluation of corrosion

There were no signs of corrosion on any sets of hooks at the completion of 24h of salt spray. On second day some greyish white buildup started to appear on the surface of all the fishing hooks, more predominantly on the surface of indigenous unbranded fishing hooks. Rust stains started to appear on the imported fishing hook first. As the salt spray exposure advanced, red/brown coloured rust buildup was visible on all the hooks. Signs of corrosion were more prominent at the point and barb. This is due to the high electric potential at the point and also due to the harbouring of salt droplets (electrolyte) at the gaps near barbs.

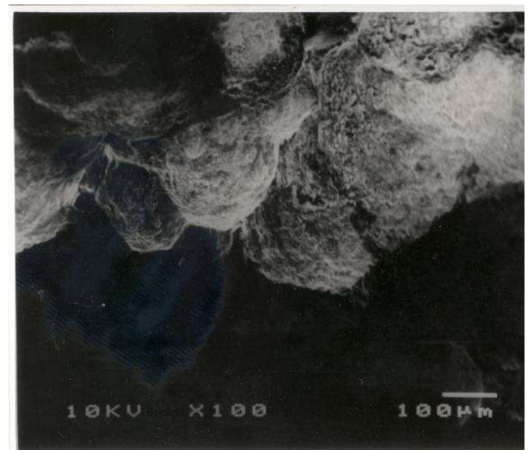
At the completion of 300h of salt spray, all hooks were almost completely rusted on the surface, without leaving much clear surface. But it was difficult to determine which hook has corroded the most by simply looking at the specimen. But after cleaning the hooks the severity of the corrosion attack on each hook was clearly visible. Evidently there was an appreciable loss of core material, which in turn affects the mechanical strength of the hook.

Figure 7.3. depicts the surface morphologies of indigenous-unbranded (a) and imported fishing hooks (b) after 300h of salt spray. In (b), it is clearly visible that large pits have developed have completely replaced the

smooth surface, whereas the surface of the indigenous-unbranded hook (a) remained more or less smooth.



(a) Surface of indigenous-unbranded fishing hook.



(b) Surface of imported fishing hook.

Fig. 7.3. Scanning Electron Micrographs (SEM) of Indigenous-unbranded and imported fishing hook exposed to 300h of salt spray (100x).

The appearance of white or grayish white buildup indicates the dissolution of tin (Sn) from the coating and formation of corrosion products of Sn on the surface. The red rust developed later indicates the complete dissolution and subsequent corrosion of underlying steel substrate (Ganesan *et al*., 2007).

7.3.1.2. Weight loss

A weight loss of 1.029 to 1.501g was observed in the imported hooks. The weight loss in Indian branded hooks varied between 0.748 and 0.753g whereas in the indigenous-unbranded hooks, it varied from 0.269 to 0.295g. After 300 h of salt spray exposure, the imported hooks recorded a mean weight loss of 9.55 %, where as the Indian branded hooks showed a weight loss of 7.64 %. However, the weight loss in indigenous-unbranded hooks was significantly low, 5.20 % ($P<0.05$). The relatively higher weight loss in imported and Indian branded hooks is indicative of reduction in their mechanical strength and sharpness.

7.3.1.3. Corrosion rate

The corrosion rates of the different types hooks analysed were calculated from the weight loss data. A comparison of corrosion resistance of Indian branded and unbranded fishing hooks and the imported branded hooks is depicted in Fig. 7.4. Initially viz., after 100 h exposure, the imported brands showed a slightly less corrosion rate compared to Indian brands. However, on continued exposure the corrosion rate of imported brands was higher than their Indian counterparts. At the completion of 100 h of salt spray the imported hook had a corrosion rate of 65.866 mpy whereas the Indian-branded hooks had a slightly high corrosion rate of 67.918 mpy. But the corrosion rate of indigenous-unbranded hooks was found to be significantly low (43.788 mpy). (Fig. 7.4.) ($P<0.05$).

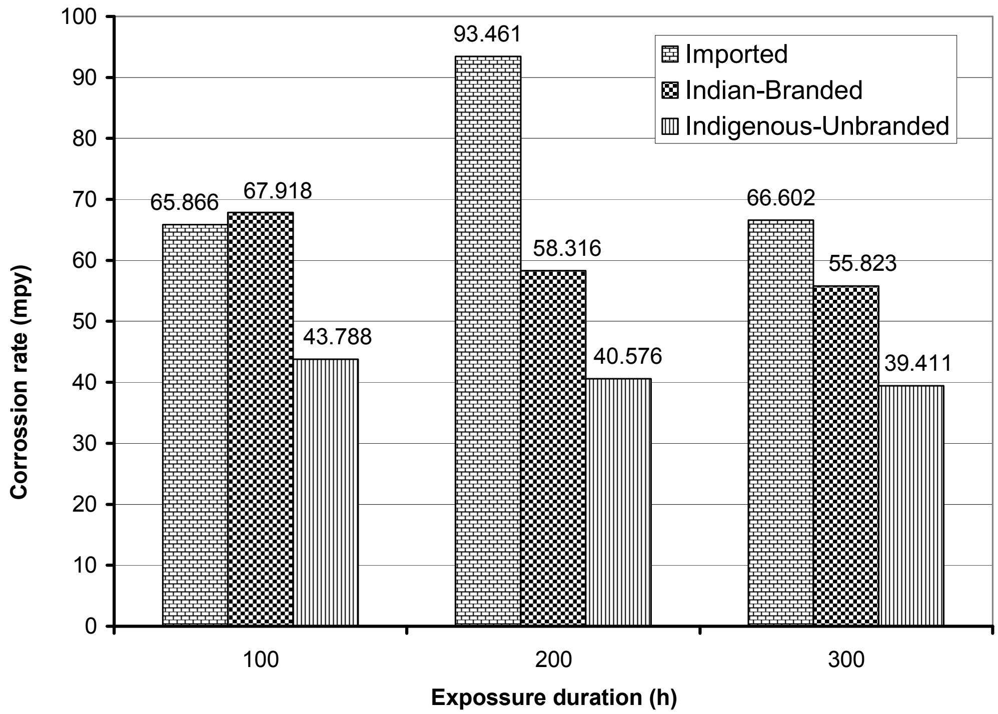


Fig. 7.4. Corrosion rates of imported, Indian-branded and indigenous unbranded fishing hooks.

After 200h of exposure the corrosion rate of imported hooks increased to 93.461 mpy, significantly differing from that of the other two groups. The Indian branded and indigenous-unbranded hooks showed corrosion rate of 58.316 mpy and 40.576 mpy respectively. This trend was maintained up to the completion of 300 h of salt spray and the corrosion rate of imported hooks was found to be 66.602 mpy and that of the Indian branded was 55.823 mpy. In the case of indigenous-unbranded hooks the corrosion rate was found to be considerably low at 39.411 mpy after completion of 300 h of salt spray.

Since all the hooks analysed in this experiment were coated with tin (Sn), the major factor that might have influenced the differences in corrosion rates could be the differences in their coating technology. As tin (Sn) is costlier than zinc (Zn) (Used in Galvanised Steels), the tinned finish for fishing hooks is generally given by electroplating method by most of the commercial manufacturers. The hot-dip method – which is a less advanced method adopted by small scale indigenous hook manufacturers - consume a lot of tin and the process inherently gives a relatively thick coating over the core metal. Tin (Sn) has a lower redox potential than iron (Fe). This material is often used as an excellent oxygen barrier for iron. However, if this coating is damaged, the iron is preferentially oxidized over the tin. As a result, the iron rusts more readily (Pi, 2004). So if the layer of tin wear away or get scratched, the presence of tin actually accelerates the corrosion of the underlying iron as shown in the reaction below.

$$\mathbf{Sn^{2+}(\mathit{aq}) + 2e^{-} \rightarrow Sn(s)\ E^{0}_{red} = -0.14\ V}$$
$$\mathbf{Fe^{2+}(\mathit{aq}) + 2e^{-} \rightarrow Fe(s)\ E^{0}_{red} = -0.44\ V}$$

Thus the tin is preferentially reduced over the iron. Therefore, the iron is preferentially oxidized over the tin (Blaber, 2000) Thus, from the results of this experiment, it is assumed that in the case of imported and Indian-branded hooks, they had a thin tin layer compared to indigenous hooks and that has been corroded away much earlier than that in indigenous hooks.

7.3.2. Effect of surface coatings on the corrosion resistance

7.3. 2.1. Visual evaluation of corrosion

All the samples on exposure to salt spray showed signs of corrosion as rust stains, blisters and corrosion product buildup on the surface. The tinned hook exhibited excellent performance as comparatively less general corrosion and pitting was noted on the surface of the samples after different intervals of salt spray exposure. The photographs of the samples before and after exposure are depicted in Fig. 7.5.

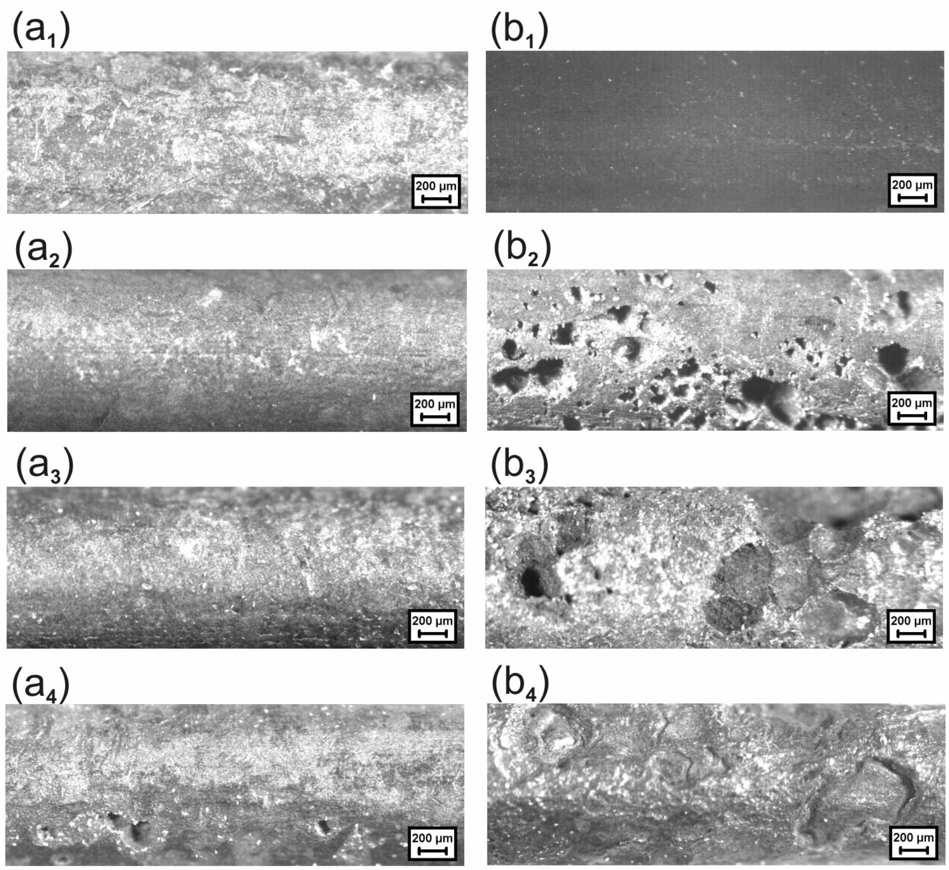


Fig. 7.5. Morphology of tinned and 'blued' hook surfaces exposed to salt spray environment.
(**a_1.** Tinned – Unexposed specimen, **a_2.** Tinned – after 100h, **a_3.** Tinned – after 200h, **a_4.** Tinned – after 300h, **b_1.** Blued – Unexposed specimen, **b_2.** Blued – after 100h, **b_3.** Blued – after 200h and **b_4.** Blued – after 300h)

Signs of corrosion started to appear from the third day in the form of rust stains on the surface of hooks. The tinned hooks had rust stains on the shanks and barbs but defects could not be seen with the naked eye but were visible when magnified under an Optical Microscope. When the tinned hooks were observed under the microscope after 300 h of salt spray exposure and subsequent cleaning, the surface looked almost smooth with a few pits (Fig. 7.5, a_4). The diameter of the hook wire did not show much reduction. The blue finished hooks showed extensive corrosion. There were blistering on the shank portion of the hook within five days of exposure. The core substrate also started corroding beneath the blisters. Comparatively higher amount of corrosion was observed along the eye, point and barb parts in most of the tinned and 'blued' hooks. Similar observation was also made by Kitano *et al.* (1990) where in, severe corrosion was seen at the eye portion of tuna long line fishhook. Some samples completely lost the barbs after 300 h of salt spray. This is due to the peculiar shape of the hooks, which facilitated accumulation of corrosive medium in the bends and nooks at these parts.

From optical microscopic analysis it was found that there was a substantial reduction in the average wire diameter of 'blued' hooks after 300 h of salt spray exposure whereas this reduction was insignificant in tinned hooks. The 'blued' hooks showed a 14.45 % reduction in wire diameter (reduced from 1.73 mm to 1.48 mm) while in the case of tinned hooks, the wire diameter was reduced by 6.90 % only (reduced from 1.74 mm to 1.62 mm). The synergetic effect of pitting and reduction in wire diameter due to corrosion could result in great loss of mechanical strength of fishing hooks that will ultimately lead to hook failures.

7.3.2.2. Weight loss

After 300 h of salt spray exposure, a weight loss of 0.063 to 0.073g was observed in the tinned hooks. The weight loss in 'blued' hooks varied between 0.228 and 0.306g. The tinned hooks recorded a mean weight loss of 5.37 %, while the blue finished hook showed significantly high weight loss of 20.54 % ($P<0.05$). A weight loss of such a high magnitude as in the case of 'blued' hooks will seriously affect the overall performance of the fishing hook.

The results of this investigation have shown that accelerated corrosion exposure causes an appreciable loss in mass of fishing hooks, which increases with increasing exposure duration.

7.3.2.3. Corrosion rate

The tinned fishing hooks had a mean corrosion rate of 26.934 mpy while the ‘blued’ hooks had shown a significantly high corrosion rate of 106.298 mpy (Fig. 7.6.) (P<0.05). The lower corrosion rate in the case of tinned hooks indicates its superior stability over blue finish against the aggressive corrosion environment in the salt spray chamber. This implies that the hooks had a uniform, non-porous tin coating. Varghese *et al.* (1997) have also reported good performance of fishing hooks coated with nickel and tin in salt spray tests.

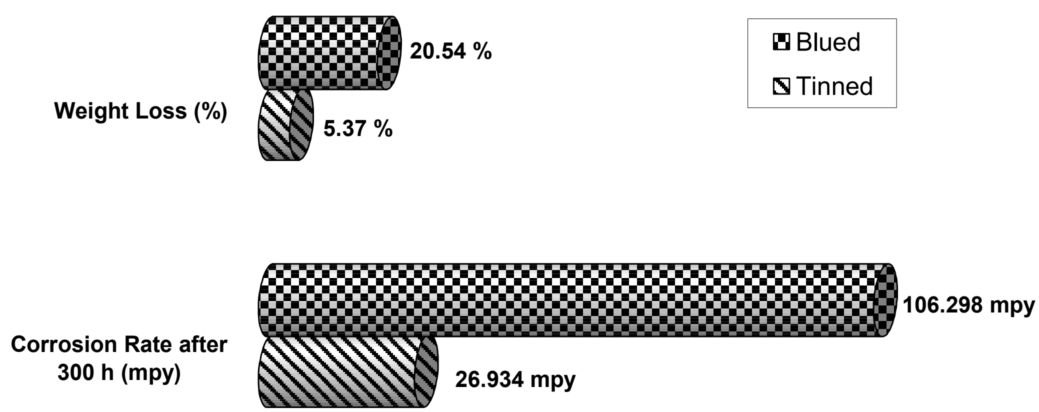


Fig. 7.6. Weight loss and corrosion rate of tinned and ‘blued’ fishing hooks after 300 h salt spray exposure.

The ‘blued’ finish apparently had poor barrier property in comparison to the tinned finish and is more prone to scratches resulting from handling. Further, the blistering observed in the case of ‘blued’ hooks is indicative of poor adhesion with the base metal which aggravated the corrosion rate.

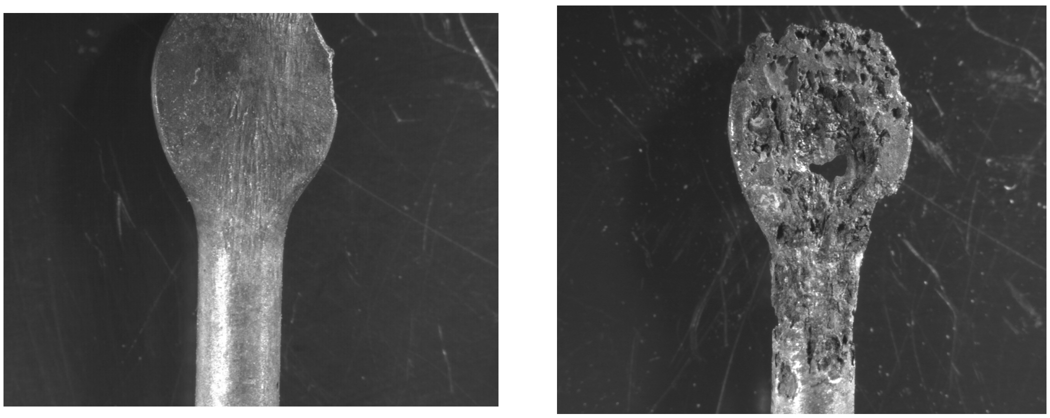
This study was based on the assumption that the general method of giving a tin (Sn) coating and the blue finish is by and large same among different manufacturers. However, there could be variance in the corrosion resistance of same type of hook finishes given by different manufacturers. Different manufacturing process and coatings are involved to produce different brands of hooks, which are generally proprietary to each manufacturer. The two types of hooks selected for this study was from a single manufacturer only.

It is clear from the study that the tinned fishing hooks are far better in resisting corrosion than 'blued' hooks. Since the tinned fishing hooks performed well in highly corrosive salt spray environment, it can be preferentially used in marine fishing.

7.3.3. Effect of snood wire on corrosion resistance

7.3.3.1. Visual evaluation of corrosion

All the fishing hooks started to show signs of corrosion within one week of exposure to salt spray. The rust stains on the surface of the hooks continued to increase as the salt spray exposure advanced. When examined at the end of 100 h of salt spray, it was found that the corrosion is spread over the entire surface of the hooks. At the end of 200 h of salt spray, the corrosion product buildup was concentrated mainly at the eye portion where the snood wire is tied to the hook. Most of the hooks rigged with the snood wire were either broken at their eye where the snood wire was tied or were at the verge of a breakage when examined after 300 h of exposure. The eye portion showed more corrosion attack as shown in Fig. 7.7. The attachment of snood wire to the hook provided enough harbouring space for the corrosive medium, which has apparently enhanced the corrosion attack in this region. Similar observations were made by Kitano *et al.* (1990) from their studies on the corrosion resistance of tuna long-line fishing hooks tied with nylon monofilament. In their study violent corrosion phenomenon was observed in the eye portion of the fishing hook. In their experiment, the eyes of the hooks were completely corroded towards the end of six months of immersion in artificial sea water.



(a) Control. (b) Hook rigged with snood wire.

Fig. 7.7. Eye portion of fishing hooks exposed to 300 h of salt spray (10x).

7.3.3.2. Weight loss

After 100 h of salt spray exposure, the control hook showed a mean weight loss of 6.16% whereas the hooks with snood wire showed a 10.08% weight loss. At the end of 300 h, this has increased to 11.53% and 20.93% respectively. The percentage weight loss after 300 h has almost doubled from that 100 h salt spray in both the cases. From statistical analysis it was found that the percentage weight loss of the hooks with snood wire is significantly different from that of control ($P<0.05$). In the experiments made by Kitano *et al.* (1990), the weight loss was in the tune of 5 to 11% after six months of immersion in artificial sea water. In fishing hooks, loss of core metal especially at the eye portion will lead to hook failures and loss of catch.

7.3.3.3. Corrosion rate

The corrosion rates were high at the initial stage of salt spray analysis. After 100 h of salt spray the control and hook with snood exhibited 96.557 mpy and 157.92 mpy respectively (Fig. 7.8.). However the corrosion rates were marginally reduced afterwards and at 200 h it figured 60.785 mpy and 79.051 mpy respectively. At the end of 300 h, the control recorded a corrosion rate of 60.214 mpy while the hooks with snood wire showed significantly higher corrosion rate of 109.316 mpy. In all the cases the hooks with snood wire has shown significantly higher corrosion rate ($P<0.05$).

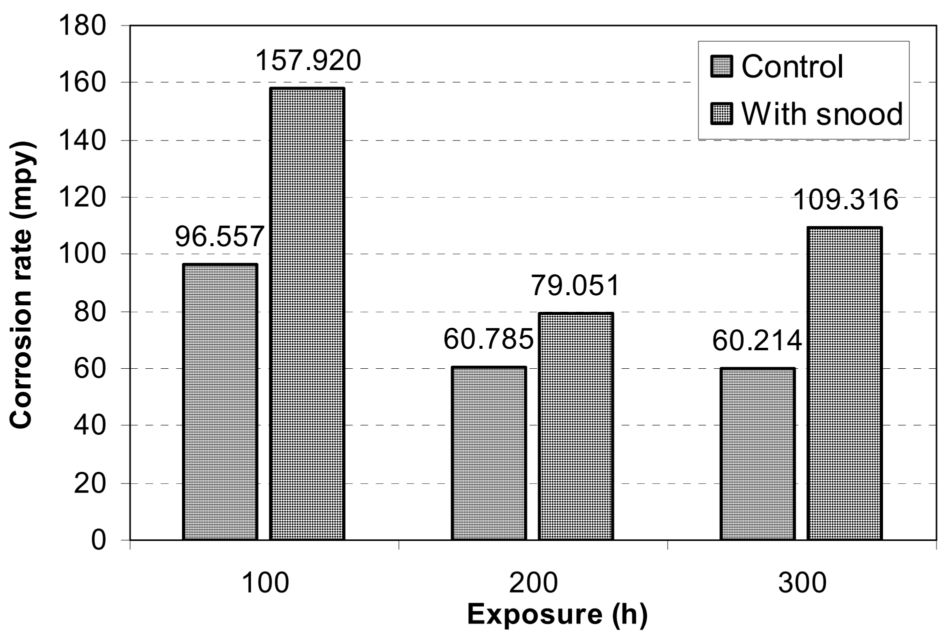


Fig. 7.8. Corrosion rate of fishing hooks tied with snood wire and control in salt spray.

The increased corrosion rate in fishing hooks with snood wire could be explained by two mechanisms. In the first case, the crevices/gaps formed at the attachment of snood wire to the fishing hook (eye portion) facilitated to hold more corrosive medium in contact with the hook surface and for a longer period of time. Similar observations were made by Kitano *et al.* (1990) in their experiments with nylon monofilament tied tuna long-line fishing hooks. Secondly, since the snood wire is also metallic, the attachment to the metallic hook constitutes a bimetallic couple, which in turn increases the corrosion rate of the fishing hooks. The snood wire used was made of stainless steel which is passive in nature and when it comes in contact with the hook leads to progressive corrosion of the hook. The synergetic effect of these two aspects results in enhanced corrosion rate in fishing hooks tied with snood wire.

This can be prevented by way of using some innovative method of attaching the snood wire to the fishing hook like using non corrosive rings which will avoid/minimize the crevices at the point of attachment and would also avoid the bimetallic corrosion. Also usage of suitable non-metallic alternative materials would also help in reducing the corrosion rate of fishing hooks where snood wires are used.

7.3.4. Effect of Cerium (Ce) treatment on the corrosion resistance

7.3. 4.1. Visual evaluation of corrosion

Signs of corrosion started to appear on the hook surfaces of both the control and treated hooks from the fifth day onwards. There was no perceivable difference in the onset of corrosion on both types of hooks. Photographs were taken before and subsequent to exposure to document the surface conditions. After 100 h of salt spray, the hooks treated with Cerium did not show much difference from that of the control hooks. The corrosion seemed to be more uniform in Ce treated hooks. But as the salt spray progressed the difference in appearance of the two type of hooks became more indistinguishable. A comparison of both the type of hooks at the completion of 300 h salt spray exposure is given in Fig. 7.9.

(a) Control. (b) Hook treated with Ce.

Fig. 7.9. Cerium (Ce) treated and control hooks after 300 h of salt spray.

7.3.4.2. Weight loss

A weight loss of 0.142 to 0.205g was observed after 300 h of salt spray exposure in the hooks treated with Cerium. On the other hand, the weight loss in control hooks varied between 0.134 and 0.186g. The hooks treated with Cerium recorded a mean weight loss of 12.03 %, and the control hooks showed a weight loss of 11.53 %. These results indicate that there was no significant difference in weight loss between hooks treated with Cerium and the untreated control hooks.

7.3. 4.3. Corrosion rate

Hooks treated with Cerium showed slightly better corrosion resistance in the initial phases of salt spray. After 100 h of exposure the Ce treated hook showed a corrosion rate of 90.810 mpy whereas the corrosion rate of the control hook had a corrosion rate of 96.557 mpy (Fig. 7.10). But this changed from 100 h onwards. At 200 h of exposure, the corrosion rates of the control hook and treated hook were 60.784 mpy and 63.577 mpy respectively. Corrosion rates remained almost same at the completion of 300h of salt spray with the control hooks figuring a corrosion rate of 60.213 mpy while that of the Ce treated hook was

62.846 mpy. On statistical analysis it was found that the difference in corrosion rates of the two types of hook was insignificant (P > 0.05). Since 98 h of salt spray is equivalent to 365 days of exposure in sea (Varghese *et al.*, 1997), it can be concluded that cerium treatment of hooks enhanced the corrosion resistance of fishing hooks equivalent to 365 days of service in actual field.

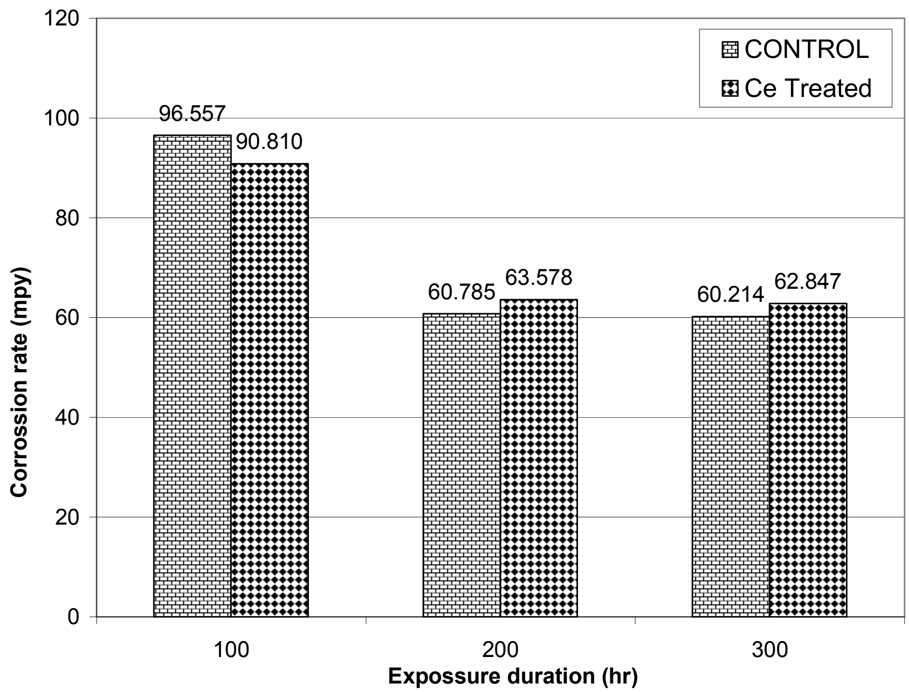


Fig. 7.10. Corrosion rate of Cerium (Ce) treated and Control fishing hooks.

Cerium ions form insoluble hydroxides, which enable them to act as effective cathodic inhibitors (Ashraf and Shibli, 2007; Bethencourt, *et al.*, 1998). In the present study it was found that there was an enhancement of corrosion resistance in the initial stages, but it failed to sustain it afterwards. According to Yu *et al.* (2001) rare earth metal oxide based surface modification of aluminium alloy creates a barrier to the supply of oxygen to the core and the supply of electron from the aluminium alloy surface to the corrosion medium. In the present case, a similar mechanism can probably exist in between the hook surface and the corrosion medium. Hence the necessary reactions of corrosion would have been suppressed, thereby reducing the driving force of corrosion in the initial stages of onset of corrosion. But this suppressive effect diminished as salt spray exposure advanced to 300 h. This indicates the poor bonding of Cerium ions on the hook surface. At the initial stages it could resist corrosion but as salt spray progresses the Cerium ions from the surface might have leached out along with the salt solution. Alternative treatment methods and incorporation of Cerium in the matrix of the core material of fishing hook during the manufacturing stage can be worked out to tackle this problem.

7.3.5. Effect of oil treatment on the corrosion resistance

7.3. 5.1. Visual evaluation of corrosion

Surface of the control hook started to corrode from the second day onwards. But it took seven days to observe clear signs of corrosion on both the type of hooks treated with oil. The progression of corrosion on the untreated hook was rapid whereas that on both lubricant oil treated and fish oil treated hooks was considerably slow and uniform. Even after 200 h of salt spray, it was difficult to visually differentiate any variations in the corrosion pattern of hooks treated with lubricant oil and fish oil. Towards the completion of 300 h of salt spray, relatively more localized corrosion attack/pitting was visible in hooks treated with lubricant oil. The corrosion on fish oil treated hooks remained uniform till the end of the experiment. Fig. 7.11. depicts both the type of hooks in contrast to the control at the completion of 300 h salt spray exposure.

(a) Control (b) Hook treated lubricant oil (c) Hook treated with fish oil

Fig. 7.11. Hooks treated with oils and control after 300 h of salt spray.

7.3.5.2. Weight loss

The control hooks exhibited a weight loss of 0.735 to 1.072g at the completion of 300 h of salt spray. Similarly, the lubricant oil treated hooks lost weight in tune of 0.534 to 0.538g. But in the case of hooks treated with fish oil, the weight loss was only 0.228 to 0.306g. On analysis it was found that the control hooks recorded a mean percentage weight loss of 8.29 % (Fig. 7.12.), whereas that of the lubricant oil treated hooks was 4.99 %. But it is remarkable to note that the weight loss was significantly low at 1.9 % in the case of fish oil treated hooks.

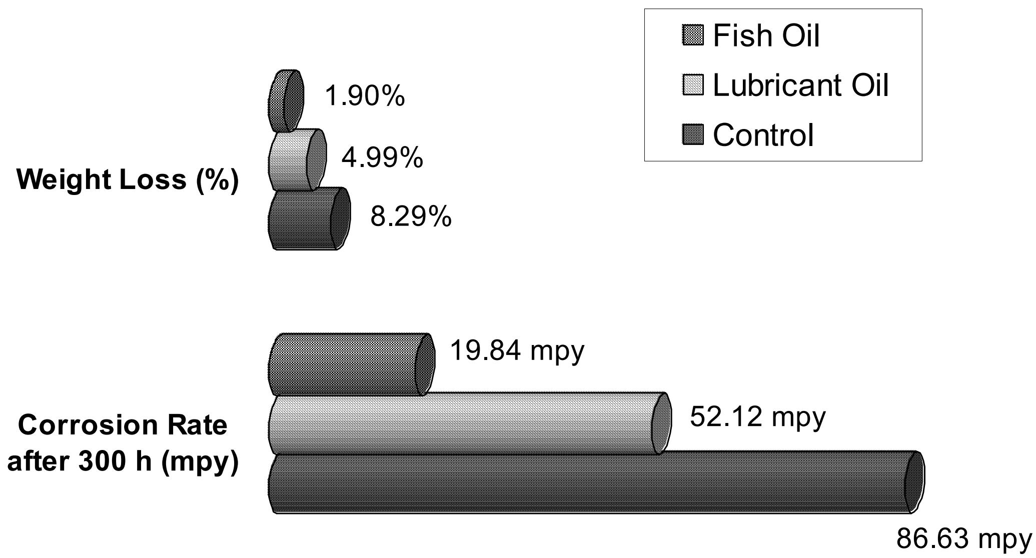


Fig. 7.12. Weight loss and corrosion rate of hooks treated with oils after 300 h salt spray exposure.

7.3. 5.3. Corrosion rate

From the initial stages onwards the corrosion rate was very low in the case of hooks treated with fish oil. After the completion of the 300 h of salt spray it was found to be only 19.84 mpy (Fig. 7.12.). On the other hand the corrosion rates of hooks treated with lubricant oil was found to be moderately high at 52.12 mpy and that of control hooks was 86.63 mpy. On statistical analysis it was found that the corrosion rate of the hooks treated with fish oil is significantly lower than that of the control ($P < 0.05$). The better corrosion protection exhibited by the fish oil treatment indicate that it could efficiently cover the entire surface of the hooks, and remained bound to the surface even in an aggressive environment such a in side a salt spray chamber.

It was found that the artisnal fisherman especially from Thoothoor region in Tamil Nadu used to apply lubricant oils, kerosene and other oils on their hooks after every use or when they have to be kept for longer periods. This practice claimed to help in extending the service life of the hooks significantly. The result of the present study confirms this. It would be also interesting to explore the effects of different types of oils applied on hooks on the behaviour/reaction of fishes towards the hooks. It is possible that some oils such as lubricant oil could repel fishes away from the hooks thus lowering the catch rates and oils such as fish oils could attract fishes towards the hook. These type response/reaction could be more observable in fishes with good sense of smell such as the sharks.

7.4. Conclusions

From the above results, the following conclusions can be drawn:

(1) Among large sized shark hooks (hook number 1, 'J' style fishing hooks), Indigenous unbranded hooks were found to be better in resisting corrosion than imported and Indian branded hooks.

(2) The tinned fishing hooks were found to be more resistant to corrosion than 'blued' fishing hooks. Since the tinned fishing hooks performed well in highly corrosive salt spray environment, it can be preferentially used in marine fishing.

(3) Fishing hook attached with steel snood wire showed significantly higher corrosion rate than that without snood wire.

(4) Treatment of fishing hooks with Cerium ions showed promising results at the initial phase, its effect is found to be diminishing over 300 h of exposure. Since 98 h of salt spray is equivalent to 365 days of exposure in sea water, it can be concluded that cerium treatment of hooks enhanced the corrosion resistance of fishing hooks equivalent to 365 days of service in actual field.

(5) Application of lubricant oil and fish oil was found to be very effective in preventing corrosion in fishing hooks exposed to salt spray. Their effect on corrosion prevention and fish behaviour in the field can be further explored.

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Chapter - 8

FISHING PERFORMANCE OF HOOKS

8.1. Introduction

The fishing efficiency of the hook is an important factor deciding the performance of any hook and line fishing gear. Hook efficiency can be expressed as the number of successful hooking divided by the number of attempts or number of fish caught divided by number of fish taking the bait (Number of bites). Hooking rate is generally expressed as the number of fish caught per hundred hooks (Gibson, 1979). The physical and mechanical properties of the hook and the biological aspects of the target fish affect catching efficiency of a hook (Lokkeborg and Bjordal, 1992). The size, shape and design of the hook are the important factors affecting the performance of a hook set against a targeted species. According to Baranov (1976) the success of the catch from a hook depends on the angle, the spear of the hook makes with the direction of the pull.

The hooking efficiency is also influenced by the size and species of the target fish (Johannessen, 1983). The responses of cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) to baited hooks were analysed by Huse and Fernö (1990) to determine their behaviour patterns, which could form the basis for improved longline hook design. The most important behaviour pattern observed for successful hooking of fish was when the fish swam away rapidly with the baited hook in its mouth, termed as the "rush" behaviour (Huse and Fernö, 1990). A hypothesis for hook design was formed, which proposes that a longline hook with its point towards the line of pull would catch more fish than a typical Atlantic longline hook with its point parallel to the line of pull. Two experimental hooks conforming to this hypothesis were compared with a standard hook in fishing experiments. Butcher *et al.* (2007) have studied performance of different designs and sizes of commonly used fishing hooks both in field and in fish cages. The study involved hooking yellowfin bream using 50 designs and sizes of commonly-configured circle and J-hooks, and a modification to a small J-hook termed the 'stop swallow'.

Few studies have been conducted on hooking rate of fishing hooks in the Indian context (Despande *et al.*, 1970; Kartha *et al*., 1973; Manohardoss, 2002; Manohardoss *et al*., 1981; Sulochanan *et al*., 1989; George *et al*., 1991 and Durai 2003). Despande *et al*. (1970) studied fishing efficiency of imported 4/0 Mustad hook whereas, Kartha *et al*. (1973) studied the effectiveness of different sizes of Mustad round bent hooks with different types of baits. Sulochanan *et al*. (1989) have analysed the hooking rate of tuna in the Arabian Sea with particular reference to yellow-fin tuna, *Thunnus albacares*. Manohardoss *et al*., (1981) and George (2002) studied the comparative fishing efficiency of Kirby bent hooks to that of round bent hooks in inland waters. George *et al*. (1991) studied relative fishing efficiencies of large sized 4/0 round bent indigenous hooks against that of imported Mustad hooks of comparable size. They studied the hooking rates of both the types and the hook's efficiency in terms of weight of fish landed, operated from a marine fishing vessel off South-West Bombay, targeting sharks. Varghese *et al.* (1997) evaluated fishing performance of indigenous unbranded hooks against that of standard control branded hooks (Mustad hooks). This was conducted through fishing experiments targeting sharks and smaller varieties of fishes.

Recently, circle hooks gained much relevance and attention of researchers owing to their ability to reduce bycatch and deep hooking – especially marine turtles - as evidenced by many research findings (Muoneke and Childress 1994; Hoey, 1996; Grover *et al*., 2002; Falterman and Graves, 2002; Prince *et al*., 2002; Skomal *et al*., 2002; Zimmerman and Bochenek, 2002; Anon, 2004a; Beckwith and Rand, 2005; Kerstetter and Graves, 2006 and Minami, *et al*. 2006). The main differences between a circle hook and a standard J-hook are their shape and the orientation of the point of the hook. Circle hooks are generally circular in shape and the point is turned inwards, pointing towards the shank of the hook (Fig. 8.1.). The point of a J-hook is generally parallel to the shank of the hook (Fig. 8.1.) (Anon, 2004a).

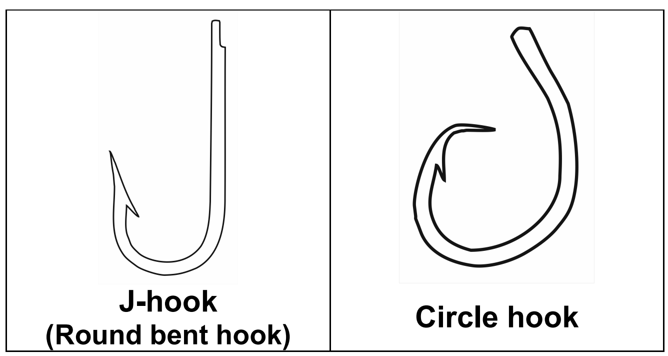

Fig. 8.1. Comparison of J-hook and Circle hook

The design of a circle hook reduces the likelihood of a hook being caught in the gut cavity or throat if swallowed (deep hooking). If the hook is swallowed, the shape of the hook allows it to slide toward the fish's jaw as the angler starts reeling, typically hooking itself in the corner of a fish's mouth. However, some studies have found that the effectiveness of a circle hook for reducing foul-hooking is compromised when the hook point is offset i.e. the point of the hook is not in the same plane as the shank of the hook (Anon, 2004a).

Circle hooks have been used for years by commercial fishers in the U.S. (IPHC, 1998) and are now increasingly being used in a number of marine catch and release fisheries. Some commercial tuna fishing vessels have switched voluntarily to circle hooks (Hoey, 1996; Falterman and Graves, 2002) indicating that circle hooks may increase tuna catch rates. The International Commission for the Conservation of Atlantic Tunas (ICCAT) has been encouraging the use of circle hooks in the Atlantic pelagic longline fisheries (Kerstetter and Graves, 2006). Use of circle hook is mandatory in the U.S. longline fishery (Federal Register 69: 40733, 2004). Primarily it is a regulatory measure taken for the reduction of sea turtle catch rate than the bycatch of pelagic fishes.

Many studies have been conducted to analyse the relationship between release mortality rates and incidence of foul-hooking associated with different hook types (A hook lodged outside of the mouth or anywhere on the exterior of a fish's body is defined as foul-hooking (Prince *et al*., 2002). Some of these studies have been focused on a single type of hook or style of fishing only, while others have compared foul-hooking rates among different types of hooks (Muoneke and Childress 1994; Malchoff *et al*., 2002; Prince *et al*., 2002; Skomal *et al*., 2002; Cooke, *et al*., 2003; Kerstetter and Graves, 2006). Many recent studies have directly compared circle hooks to similar sized J-hooks/round bent hooks (Muoneke and Childress 1994; Grover *et al*., 2002; Anon, 2004a). These studies have examined a variety of species ranging from billfishes and pelagics to gamefishes, such as red drum and striped bass etc. However no such studies have been conducted in the Indian context involving circle hook and locally available fish species.

Recent international research on the effect of hook type and survival was confined to the recreational fishery where 'catch and release' fishing practice is common (Malchoff *et al*., 2002; Prince *et al*., 2002; Skomal *et* *al.*, 2002). Beckwith and Rand (2005) investigated the incidence of deep hooking by applying different treatments of terminal tackle during fishing trials. They have studied the probability of deep hooking using three different sizes of circle hooks against a standard 7/0 J-style hook treatment along with different leader and weight configurations.

Prince *et al*. (2002) compared the performance of circle hook and "J" hook in recreational catch-and-release fisheries for billfish. This study was carried out in response to requests for more information on the use of circle hooks for catching billfish, to promote the live release of these important resources (USDOC, 1999). In this study the hooking and catch percentages between terminal tackles (circle and “J” hooks) used in the trolling/pitch bait recreational fisheries for billfishes and sailfishes were compared. They found that circle hooks used for sailfish had a hooking percentage 1.83 times higher than “J” hooks. More sailfish were hooked in the corner of the mouth using circle hooks (85%), as compared with “J” hooks (27%). On the other hand, 46% sailfish were deep hooked in the throat and stomach with “J” hooks, as compared with circle hooks (2%). Only 1% was foul hooked using circle hooks, while 9% sailfish caught on “J” hooks were foul hooked. In this study it was found that the sailfish caught on “J” hooks are 21 times more likely to suffer hook-related bleeding than those caught on circle hooks. Minami, *et al*. (2006) studied the effect of circle hooks and feasibility of de-hooking devices to reduce incidental mortality of sea turtles in the Japanese longline fishery.

Many imported branded hooks are popularly used all over India along with the Indian hooks. Popularity of recreational angling using hooks is also on the rise in India. Regardless of all these, there is scarcity of sufficient and dependable data as detailed studies on the fishing performance of different types of fishing hooks in the Indian context are very limited. Hence, this study has been taken up with the following objectives:

1. To compare the fishing performance of imported and Indian hooks.
2. To compare the fishing performance of circle and ‘J’ hooks.
3. To compare the difference in hooking locations and severity of wound/injuries between circle hooks and standard J-style round bent hooks.

8.2. Materials and Methods

8.2.1. Study area and period

The experiments were carried out from January 2007 to April 2008 in different water bodies viz., freshwater, brackish water and marine, in Kerala state. Diverse water bodies were selected as different water bodies have different types of fishes which may exhibit varied behaviour towards hook types selected for the study. Experimental fishing was conducted at eight different fishing locations namely, Thevara, Thoppumpady, Fort Cochin, Vypeen, Njarackal, Muvattupuzha in Ernakulam district, Thodupuzha in Idukki district and Padanilam in Kollam district (Fig. 8.2.) with the help of local fishermen in these areas.

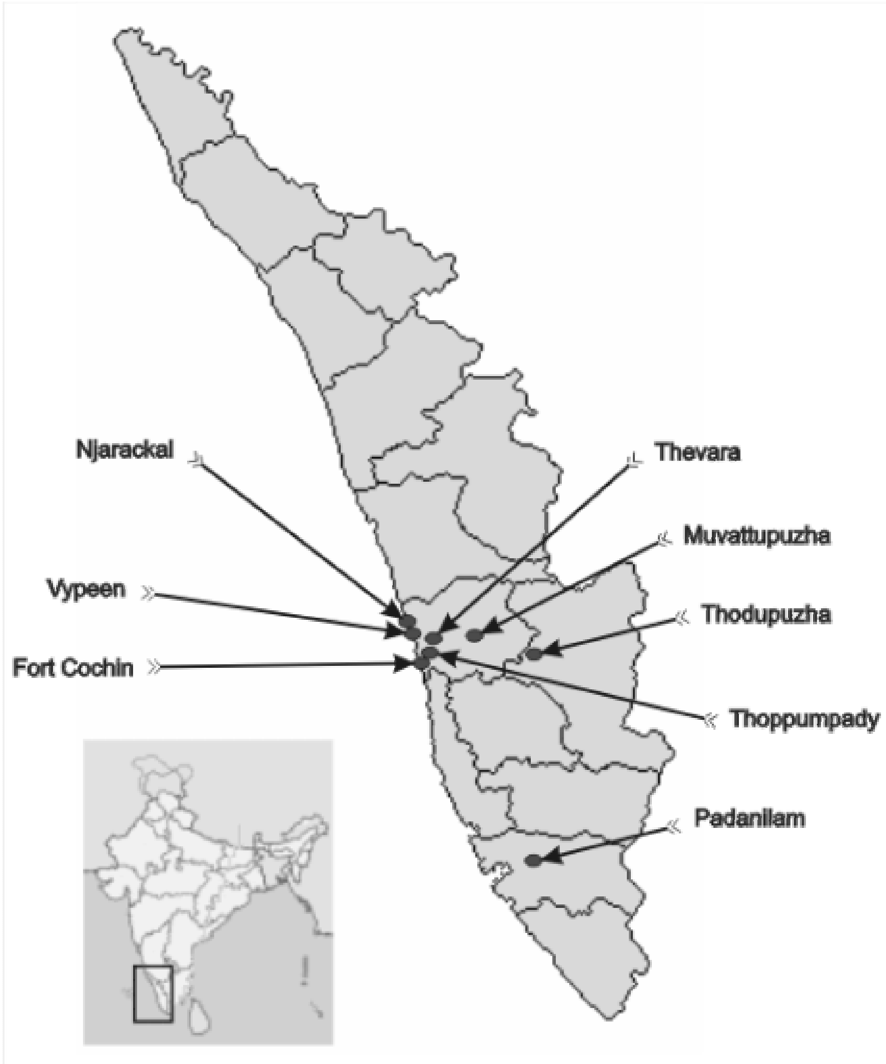

Fig. 8.2. Map showing the study locations

8.2.2. Gear configuration

The experimental fishing was carried out with handline fishing gear configuration using the selected hooks as the terminal gear. The gear configuration used was identical with the handline configuration used by the artisanal fishermen in the areas where this study has been carried out (Fig. 8.3.). Polyamide monofilament yarn of 0.8 mm diameter was used as the line. The hook was rigged at one end of a leader line of about 50 cm length as per Beckwith and Rand (2005), which in turn was connected to a leaded swivel to avoid entangling of the line. One end of the swivel was connected to the main line. Only single hook was rigged to the gear.

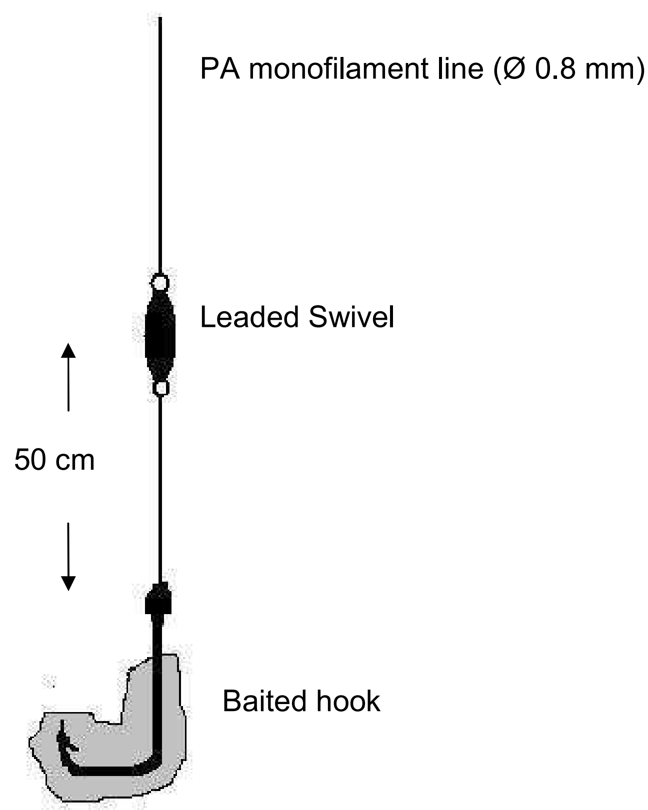

Fig. 8.3. Schematic diagram of the handline gear configuration used

Different types of natural dead baits such as oil sardine, chicken waste and dough bait, the popular baits used in the study area were used to bait the hooks. Care has been taken to operate the two types of hooks in identical conditions, using the same type and size of bait to avoid interferences due to difference in bait types, sizes and location. Depth of operation varied from place to place. It was adjusted according to the water body where the gears were operated and also the targeted fish species. However, both the type of hooks were operated at same area and depth for a given trial.

The baited handlines were cast concurrently in the same location. Each casting was recorded as one attempt. The number of bites, number of successful hooking, location of hooking injury on fish's body, severity of wound and the type of fish caught were recorded. A fish bite was considered to be a strike that resulted in the line being pulled out of the water, or when a bite is witnessed visually. Injuries due to hooking were assessed by evaluating hooking location, as well as incidence and amount of bleeding observed. Hooked fish was pulled out of the water, the mouth opened, and the hook location and amount and source of bleeding were noted. Locations of hooking were categorized as 'lip hooked', 'deep hooked' and 'foul hooked'. The term 'lip hooked' is used when the hook is lodged at any part of the lip/jaw portion of the fish. The term 'deep hooked' is used to indicate hooks lodged deep inside the mouth, throat or deeper in the alimentary tract. The term 'foul hooked' was used to indicate a hook lodged outside of the mouth or anywhere on the exterior of a fish's body (Anon, 2004a). The severity of wounds was classified based on the bleeding observed in the captured fish after removal of the hook on a four point grade scale from 0 to 3 as per Rapp *et al.* (2008) (Table 8.1.).

Table 8.1. Classification of bleeding

Occurrence of bleeding	**Scale/ Score**
No bleeding	0
Light bleeding	1
Medium bleeding	2
Severe bleeding	3

Based on this score injury of a fish is categorized in to 'minor', moderate' and 'severe'. A wound was classified as of 'minor' severity if there was a score of 0 (no bleeding) or 1 (light bleeding). Likewise, wounds with score 2 (medium bleeding) were categorized as 'moderate' and those with score 3 (severe bleeding) were categorized as 'severe' (Malchoff *et al*., 2002).

8.2.3. Comparative fishing performance: Indian Vs imported fishing hooks

Preliminary surveys were conducted at various fishing centers of different water bodies of Kerala to identify the common types of fishing hooks used and their operations. It was found that straight shank J-style hooks (round bent) are the most common type of fishing hook used in Kerala. Hence, two most popular commercial brands of the J-style hooks used by the local fishermen were selected for this study. The selected brand of imported fishing hook was named as 'Imported' and the Indian hook was named as 'Indian' for this study. The number 9 hooks were selected as they are commonly used by the fishermen in the study area. The physical and mechanical properties of the hook used are given in the Table 8.2.

Table 8.2. Properties of hooks used for the fishing performance evaluation

	Indian Hook	**Imported Hook**
Hook number/Size	9	9
Wire Diameter (mm)	1.49	1.45
Gape (mm)	12	13
Bite (mm)	13.4	14.2
Total Length (mm)	33.1	31.8
Weight (g)	0.791	0.710
Unbending Load (N)	292.317	213.286

A total of 287 operations were carried out with both the hook types. The results of each operations and corresponding observations were recorded and analyzed. From the data, hooking rate per hundred hooks was calculated which is used to compare the efficiency among the two types of hooks experimented.

8.2.3.1. Calculation of hooking efficiency

In order to allow a preliminary comparison of the hooking efficiencies of the different hooks studied, catch per unit effort (CPUE) and hooking rates were calculated. CPUE was calculated as number of fish caught per 100 hooks (Gibson, 1979; Falterman and Graves, 2002; Zagaglia *et al*., 2004) as per the following formula:

Catch per unit effort (CPUE) = (number of fish caught/number of hooks deployed) x 100

Similarly, the hooking rate was expressed as the ratio of number of successful hooking divided by the number of fish bites (Prince *et al*., 2002).

Hooking rate = (number of fish caught/number of bites) x 100

A strike that resulted in the line being pulled out is considered as a fish bite.

8.2.4. Comparative fishing performance: Circle hooks Vs 'J' style hooks

The fishing gear configuration used in this study was as per Fig. 8.3. except for the line diameter and terminal gear (hook) used. PA monofilament line of 1.0 mm diameter was used as the size of hook used was larger. Circle hooks and J-hooks of comparable size were used as the terminal gear and their fishing performance were evaluated. Circle hook styles and sizes are not consistent between models, and they do not correspond to hook size numbering of traditional “J” hooks. Non-offset circle hook of 9/0 size and straight shank “J” hook of number 6 size were selected. The physical and mechanical properties of the hook used are given in the Table 8.3. Though the commercially-listed sizes of the two hooks used in this study were different, the actual sizes of the hook types were almost identical.

Table 8.3. Properties of hooks used for the fishing performance evaluation of Circle hooks and ‘J’ style hooks

	Circle hook	**‘J’ style hook**
Hook number/Size	9/0	6
Wire Diameter (mm)	2.35	2.06
Gape (mm)	18.60	17.40
Bite (mm)	18.10	19.50
Total Length (mm)	28.30	42.90
Weight (g)	2.387	1.983
Unbending Load (N)	814.294	551.863

These hooks were rigged, baited and operated in the traditional way except for the hook setting technique. The traditional hook setting technique of jerking the fishing line was used for “J” hooks while, the circle hooks were operated in a more passive approach, by simply reeling the line tight as the fish swims away with the bait. This modification was done according to the design peculiarity of the circle hooks and their mode of hooking.

8.2.5. Statistical analysis

Statistical analyses were performed using Statistical Package for the Social Sciences (SPSS, version 10) and test results were considered significant at the 5% confidence level (i.e., $P < 0.05$). One-way Analysis of Variance (ANOVA) test was used to assess the relationship between the different types of hook combinations experimented.

8.3. Results and Discussion

8.3.1. Comparative fishing performance: Indian Vs imported fishing hooks

8.3.1. 1. Hooking efficiency

Out of the 287 operations conducted, the imported brand was able to land 37 fishes out of 261 bites, while the Indian brand managed to land 33 fishes out of 266 bites. Different species of fishes caught in the experimental fishing operations are listed in Table 8.4.

Table 8.4. Fishes caught during experimental hook and line operations

Sl. No.	Common Name	Scientific Name	Local Name
1	Cat fish	*Arius Spp.*	Aetta
2	Indian mottled eel	*Anguilla bengalensis bengalensis*	Malanjil/ Mananjil/Malan/ Aarel
3	Snapper	*Lutjanus Spp.*	Chembally
4	Tilapia	*Oreochromis mossambicus*	Tilapia/Tilopia/Thilopia/ Silopia
5	Pearl spot	*Etroplus suratensis*	Karimeen
6	Freshwater garfish	*Xenentodon cancila*	Kolan
7	Banded Snakehead	*Channa striatus*	Bral/ Varal/Varaal
8	Fresh water cat fish	*Wallago attu*	Attu valah/Valah
9	Walking Catfish	*Clarias batrachus*	Mushi/Muzhi

The imported hook had a CPUE of 13.31 (No. fishes caught/100 hooks) while the Indian hook had a CPUE of 11.87. The hooking rates were 14.18% and 12.41% for the imported and Indian hooks respectively (Fig. 8.4.). There was no significant difference in hooking rate of the two types of hooks ($P > 0.05$) indicating that Indian hooks are at par with imported hooks in terms of fishing performance.

This result is in agreement with a similar study conducted by George *et al.* (1991) in which both Indian and imported hooks were found comparable in fishing efficiencies. Their study showed that the imported hooks had a hooking rate of 6.63% while the indigenous hooks had a slightly higher hooking rate of 6.83%. Though both the type of hooks were comparable in terms of hooking efficiency, the Indian hooks were more fragile and liable to deformation under load when compared to the imported hooks.

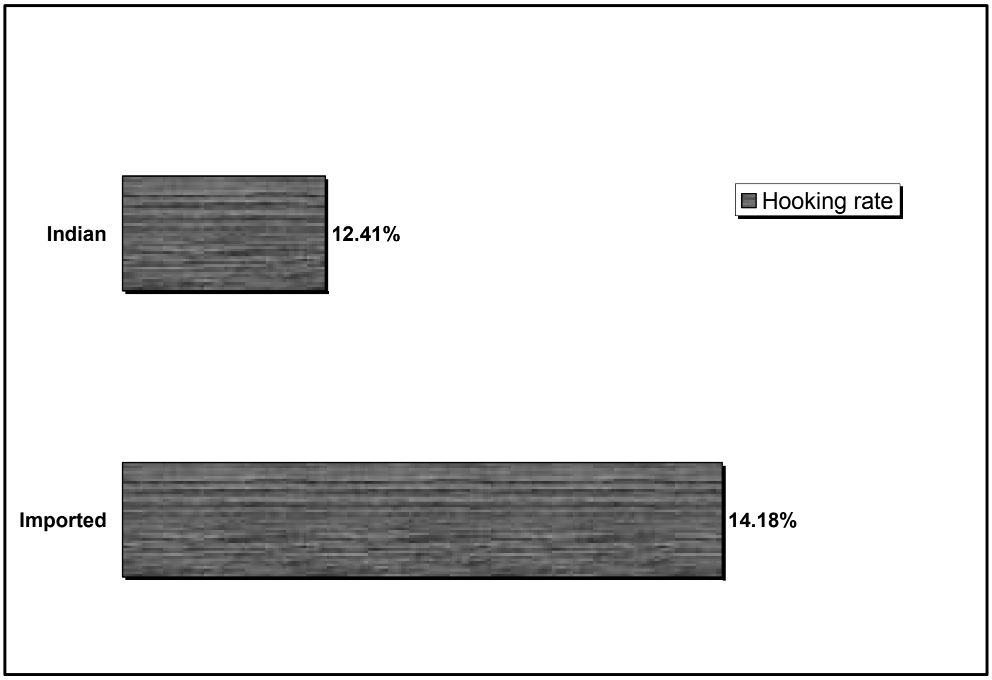

Fig. 8.4. Hooking rate of imported and Indian fishing hooks

In a fishery resource survey of the Indian Exclusive Economic Zone (EEZ) around Andaman and Nicobar Islands during August 1989 to December 2002, the overall hooking rate recorded for tuna hook was 1.85% (John *et al.*, 2005). Sulochanan *et al.* (1989) reported that the catch index for all tuna and that separately for yellow-fin tuna was 1.54% and 1.43% respectively. Anderson and Waheed (1990) have reported that the hooking rate for the shark longline was about five per 100 hooks (5%) and that for tuna longline was only one per 100 hooks (1%). In this study, they used standard round bent hooks and tuna hooks respectively for the shark longline and tuna longline. George *et al.* (1991) have compared the hooking rate of sharks for the 4/0 round bent indigenous hooks along with imported Mustad hooks and found that both the hooks are comparable in hooking rate. These experiments were conducted with shark longline operated from M. V. Saraswathy of CIFE, Bombay in and around Angrea Bank and off southwest Bombay. The hooking rate of the present study is almost double that of the hooking rates reported in some other studies.

Varghese *et al.* (1997) have reported a hooking rate of 6.83% for indigenous unbranded hooks and 6.63% for imported Mustad hook used as control in their fishing experiment targeting sharks and smaller varieties of fishes.

8.3.1. 2. Hooking location

The hooking location remained generally the same for the two types of hooks used. Out of the 37 fishes caught with the imported hook, 18 fishes (48.65%) had the hook lodged in the lip (Fig. 8.5.). Similarly, about 37.84% fishes were deep hooked (Fig. 8.6.) and about 13.51% were foul hooked. In most of the deep hooked fishes, the hook had injured the esophagus and the de-hooking process was difficult due to the deep location of the hook. A graphic representation of percentage occurrence of different hooking locations is given in Fig. 8.7.

Fig. 8.5. Lip hooked fish (Hook lodged on the lower jaw)

Fig. 8.6. Deep hooked fish (Hook lodged deep inside the mouth)

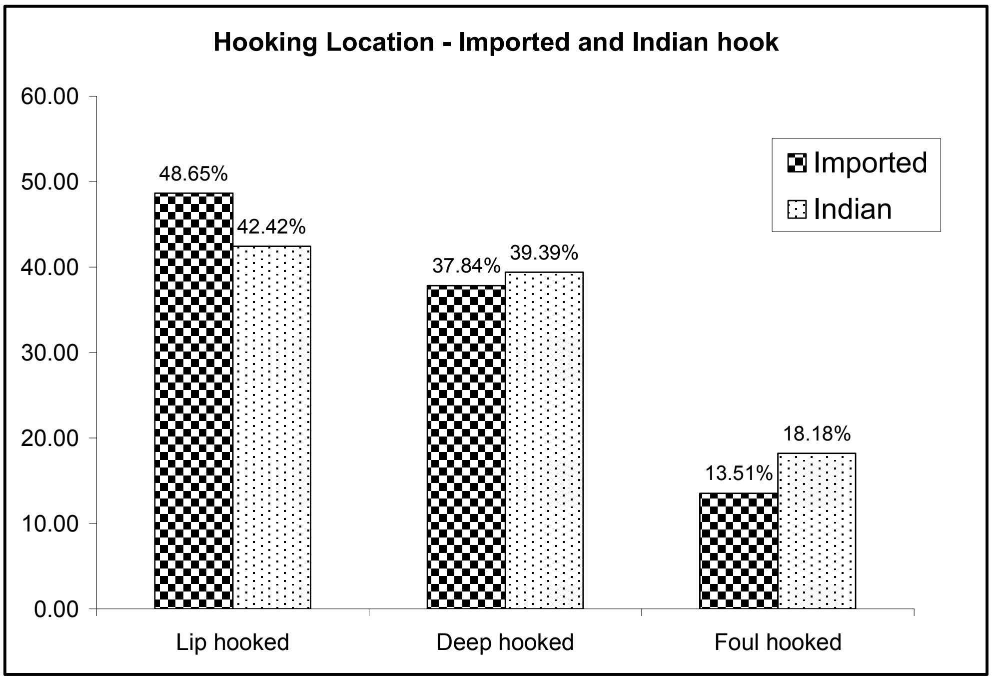

Fig. 8.7. Percentage occurrence of hooking locations – imported and Indian hook

In the case of Indian hook, the percentage occurrence of lip hooked, deep hooked and foul hooked fish were respectively 42.42%, 39.39% and 18.18% (Fig. 8.7.). There was no significant difference between the two types of hooks experimented in terms of hooking location. In the study by Skomal *et al*. (2002) fifty-two percent of the bluefin tuna caught on straight ("J") hook were hooked in the jaw, and thirty four percent were hooked in the pharynx or esophagus.

The hooking location is an important factor determining the survival of the fish during and after release, in the case of catch-and-release fishery. Deeply hooked fish of any species generally suffer higher mortality than shallow-hooked fish (Muoneke and Childress 1994). Zimmerman and Bochenek (2002) have found that hooking of fish in the esophagus/gill area contributed to high mortality after release. Many studies indicated that fish caught by hooks are generally hooked either in the mouth, particularly in the jaw or in the alimentary tract if the hooks are swallowed (Lokkeborg *et al*., 1989; Huse and Fernö, 1990; Lokkeborg and Bjordal, 1992). Many factors such as the size and type of the hook, type of fish caught, fishing method/setup used etc. can influence the location of hooking. An overall low incidence of deep hooking has been reported by Beckwith and Rand (2005) in instances where the hook and line is operated from shore in tidal inlets and marine systems with more active currents. Fishes caught in the mouth or jaw would suffer less physical damage and presumably have higher rates of survival after release (Kerstetter and Graves, 2006).

A unique experiment by Willis and Millar, (2001) by adding a wire to a hook on the side opposite to the tip (bite), with an angle of around 45 degrees from the shank, made the hook wider without affecting the biting end. This has reduced gut hooking in fishes, and it may also help to reduce deep hooking in sea turtles (Bayliff, 2007). According to Beckwith and Rand (2005), the probability of deep hooking of 7/0 J-style hooks with a shortened length of leader with a fixed weight was reduced by a factor of two regardless of the style of the hook.

8.3.1. 3. Severity of wound

The severity of the wound caused by the hooking has a decisive role in determining the hooking mortality rates of fishes. In this study, about 10.81% of the total fish caught with the imported fishing hook suffered only minor injuries, while 45.95% suffered moderate injuries and 43.24% had severe injuries due to hooking (Fig. 8.8.). On the other hand, about 9.09% fishes caught on the Indian fishing hooks had minor injuries, 42.42% had moderate injuries and 48.48% suffered severe injuries (Fig. 8.8.). The Indian hook exhibited slightly higher rate of severe injuries and remarkably they had slightly high incidence of deep hooking also. However, the differences were found to be statistically insignificant.

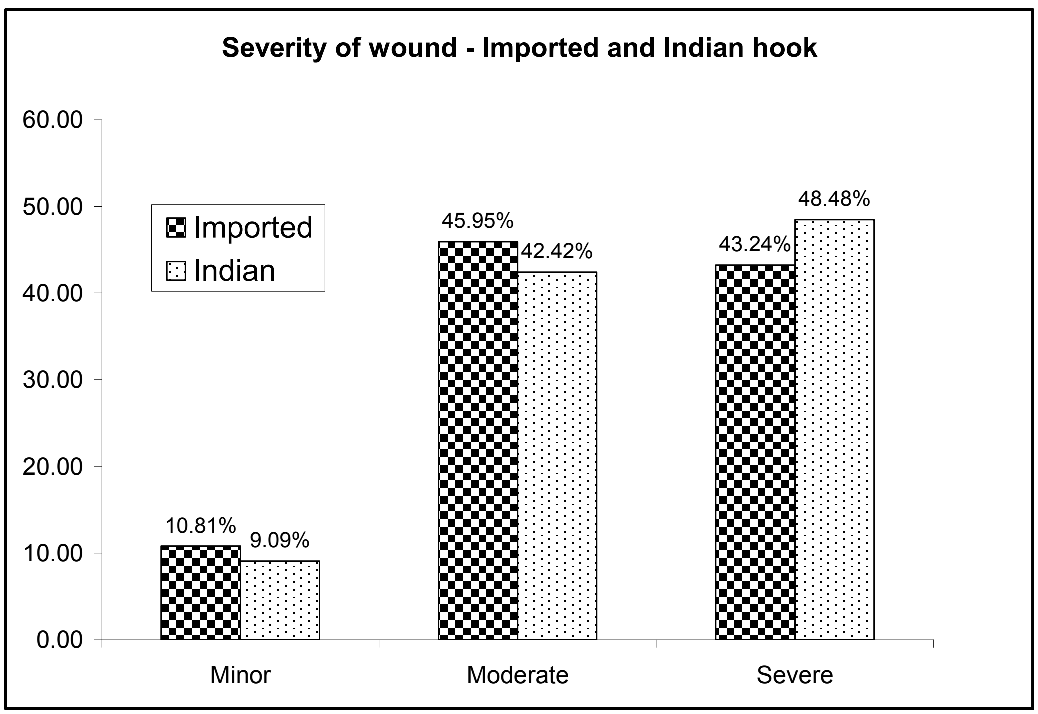

Fig. 8.8. Percentage of severity of wounds – imported and Indian hook

Grover *et al.* (2002) confirmed that the post release mortality rates depended strongly on hook wound location. Injuries to internal organs as a result of deep hooking or hooking in locations other than the mouth substantially increase release mortality (Anon, 2004a). Lukacovic and Uphoff (2002) reported that catch-and-release mortality is influenced by hook location, bait and hook type, angler experience, and season, based on their studies on striped bass (*Morone saxatilis*). Lukacovic (1999) reported a mortality rate of 9.1% for fish caught on conventional hooks while it was only 0.8% for the fish caught on circles hooks. Grover *et al*. (2002) observed that among different fishes caught on hooks kept under observation, only gut-hooked fish died within 24 hours of holding, while in lower-jaw hooked fish mortality was observed only after 24 hours of holding.

On the other hand, in a catch-and-release fishing mortality study, comparing circle hooks to similar sized J-hooks conducted by Florida Fish and Wildlife Conservation Commission on Tarpon fish, regardless of the hook type, post-release mortality was equal among different fishing methods and appeared to be unrelated to hook type (Anon, 2004a). Similar observations were also made by Malchoff *et al*. (2002) that hook type was not a significant factor in the prediction of mortality.

8.3.2. Comparative fishing performance: Circle hooks Vs 'J' style hooks

8.3.2. 1. Hooking efficiency

A total of 178 fishing operations were carried out with both circle and conventional J-hooks. The J-hooks caught 14 fishes out of a total of 90 fish bites experienced during the experimental fishing. The hooking rate was very low in the case of circle hooks with only 9 fishes caught out of 104 bites experienced.

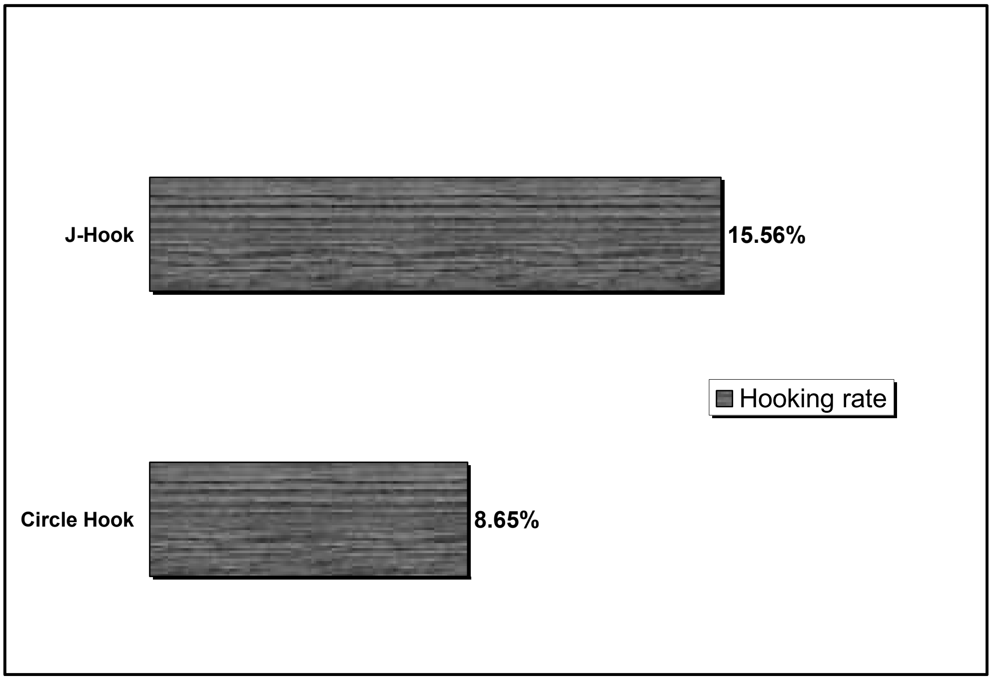

Fig. 8.9. Hooking rate of circle and J-style hooks

The catch per 100 hooks (CPUE) of the circle hooks was 5.06 whereas the J-hook registered a CPUE of 7.87. Similarly, the circle hooks showed a hooking rate of 8.65% while the J-hook had a higher hooking rate of 15.56% (Fig. 8.9.). The circle hooks showed significantly lower ($P < 0.05$) hooking rate compared to the “J” hooks.

The results are found to be in disagreement with many other studies conducted elsewhere. In the comparative study of circle hooks against “J” hooks by Falterman and Graves (2002) the circle hooks had a higher CPUE of 5.05 in contrast to 2.28 observed in the case of "J" hooks. The CPUE was approximately 2.5 times higher with circle hooks as compared with J-hooks when only the targeted tuna was taken into consideration (3.33 tuna/100 hooks). Prince *et al*. (2002) reported that circle hooks used on sailfish had hooking percentages that were 1.83 times higher compared with "J" hooks. However it may be noted that all these studies were conducted on larges sized tuna/tuna like fishes while the present study was conducted using handline operated from shore and the targeted fishes were largely small sized in comparison to the large sized pelagic fishes. Moreover, larger hooks require a stronger force to allow the hook to fully penetrate the inside of the mouth cavity (Johannessen, 1983) and the size of the fish striking the fishing hook has an important role in deciding a successful catch.

8.3.2. 2. Hooking location

Unlike in the case of previous experiment, the hooking locations varied widely between the two hook types (Fig. 8.10.). In the case of circle hooks, 77.78% of the fish caught were hooked at the lip and only 22.22% fishes were deep hooked. There was no foul hooked fish with circle hook during the experimental fishing. In a study reported in 2004 on striped bass, foul hooking was significantly less in circle hook than in J-hooks viz., 1.5% vs. 15% (Anon, 2004a).

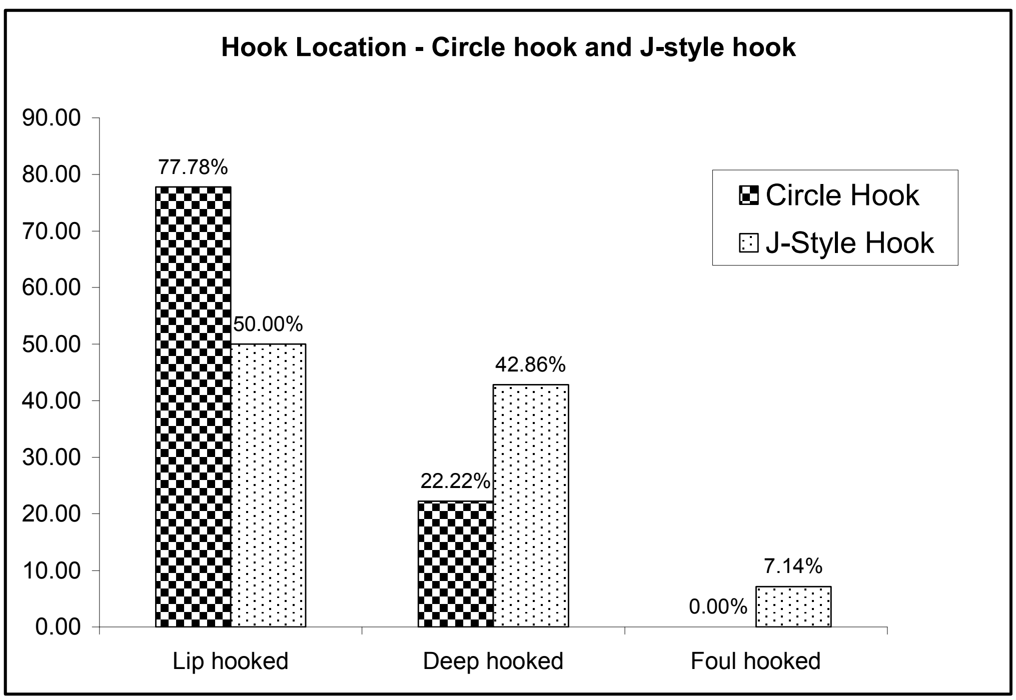

Fig. 8.10. Percentage occurrence of hooking locations – Circle hook and J-style hook

In contrast, only 50% of fishes caught with the J-hook were lip hooked, 42.86% deep hooked and 7.14% were foul hooked. On statistical analysis it was found that there is significant difference between the two types of hooks in terms of hooking location ($P<0.05$). The percentage occurrence of hooking locations and severity of wounds observed in this study are given in Table 8.5. It was observed that, in most of the fishes caught with the circle hook, the hook found to be lodged at one corner of the mouth opening.

Similar results were reported by Prince *et al.* (2002). In their study, significantly higher number of sailfish were hooked in the corner of the mouth using circle hooks (85%) compared with "J" hooks (27%). In contrast, significantly more sailfishes were deep hooked in the throat and stomach with "J" hooks (46%) compared to circle hooks (2%). Only one sailfish (1%) was foul hooked using circle hooks, while 11 (9%) sailfish caught on "J" hooks were foul hooked. Sailfish caught on "J" hooks were 21 times more likely to suffer hook-related bleeding than those caught on circle hooks.

The frequency of deep hooking increased when J-hooks were used (Anon, 2004a). Beckwith and Rand (2005) observed that the use of intermediate size (14/0) circle hooks with a short leader and a fixed weight reduced deep hooking incidence by a factor of five. The lowest incidence of deep hooking of 4% was achieved using large or intermediate size circle hooks on short leaders with fixed weights. Deep hooking can be lethal to the fish caught as it causes severe internal injuries and excessive bleeding which can cause physiological stress and reduced growth (Muoneke and Childress, 1994; Cooke *et al*., 2003; Beckwith and Rand, 2005). This aspect is very important in catch-and-release fisheries.

Falterman and Graves (2002) observed that circle hooks consistently had a higher frequency of jaw hooking and a lower frequency of gut hooking than J-hooks. In their study, 95% of the fish caught with circle hooks were hooked in the jaw. Skomal *et al*. (2002) reported that there was a significant association between hook type and hook location. They observed that 94% of the bluefin tuna caught on circle hooks were hooked in the jaw, and 4% were hooked in the pharynx or esophagus. Lukacovic and Uphoff (2002) observed only 10.6% fish deeply hooked on circle hooks in comparison to 45.6% on standard 'J' hooks. According to Zimmerman and Bochenek (2002) there was no statistical difference between circle hook and standard hook sets for both hook set location and release condition (P=0.05). However, the instances of gut hooked summer flounder were lower (4.7%) in fish caught with circle hooks than in fish caught with standard J-hooks (15.6%) (Zimmerman and Bochenek, 2002).

8.3.2. 3. Severity of wound

Higher incidence of minor injuries was observed in the case of fish caught with circle hooks (66.67%). About 22.22% of fishes suffered moderate injuries and only 11.11% suffered severe injuries with circle hooks (Fig. 8.11.). In contrast, 21.43% of fish caught using the conventional J-hook had minor injuries, 35.71% had moderate injuries and 42.86% had severe wounds (Fig. 8.11.).

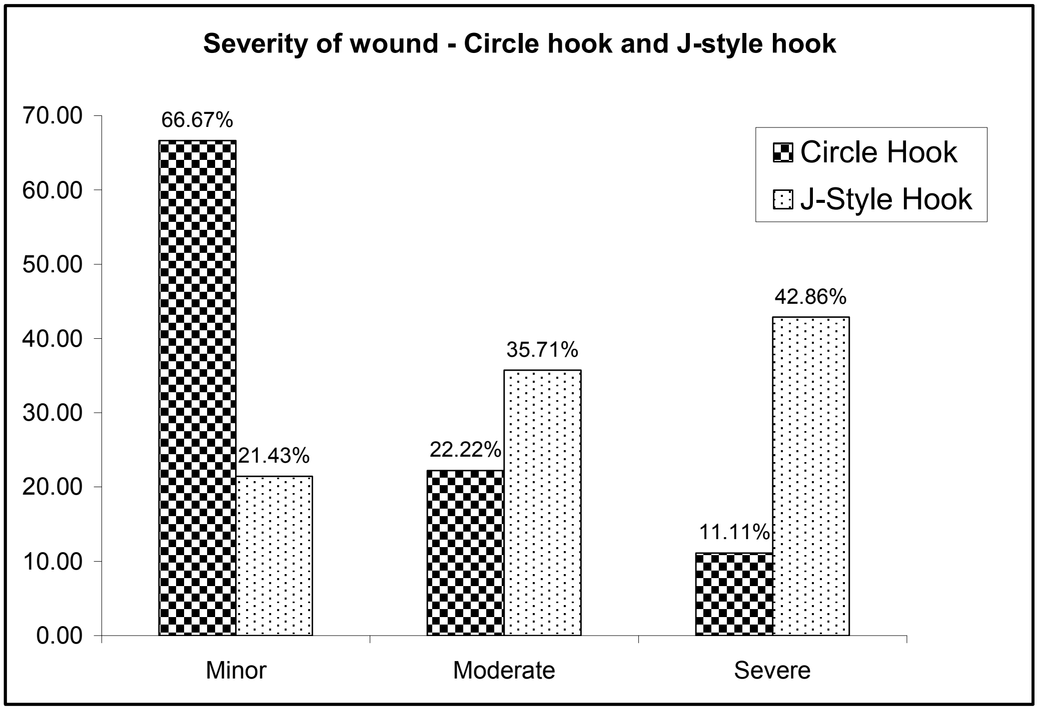

Fig. 8.11. Percentage of severity of wounds – Circle hook and J-style hook

The differences in the severity of wounds observed in the two types of fishing hooks were found to be statistically significant at 95% confidence level ($P < 0.05$).

In the experiments carried out by Zimmerman and Bochenek (2002) more than 80% of the hook sets on circle hooks occurred in the upper and lower jaws (minor injuries). Only 1.6% experienced gill damage, 4.7% experienced gut damage, and 12.5% experienced bleeding. In the case of fish caught with the standard J-style hooks, 77.1% were easily unhooked with no damage, 2.1% had gill damage, 11.5% gut damage, and 9.4% exhibited bleeding.

Owing to the low incidence of severe injuries, circle hooks seem to be a promising type of hook to reduce release mortality (Anon, 2004a) as the hooked fish remains alive for long, till they are taken out. These hooks are designed to move to the corner of the fish's mouth and set themselves as the fish swims away. The more a fish swims away from the pull point, the more likely the hook will move to the rear corner of its mouth. (Anon, 2005a). In a study conducted in 1999 Lukacovic reported a release mortality rate of 9.1% for fish caught on conventional hooks whereas it was only 0.8% for the fish caught on circles hooks.

Similarly, significantly lower release mortality in striped bass when using non-offset circle hooks, as opposed to conventional “J” hooks is reported (Lukacovic, 1999, 2001; Lukacovic and Uphoff, 2002). Studies by Prince, *et al.* (2002) on billfish, Skomal, *et al.* (2002) on bluefin tuna, Falterman and Graves (2002) on yellowfin tuna, and Trumble, *et al.* (2002) on Pacific halibut also showed significant decrease in release mortality while using circle hooks. Cooke, *et al.* (2003) reported that circle hooks can be used for reducing release mortality in rock bass. While on bluegill and pumpkinseed there was no significant benefit by using them.

The practice of catch-and-release is becoming increasingly common in recreational fishery in recent days (Beckwith and Rand, 2005). Researchers are working on different methods to reduce the negative impacts of recreational fishing. Efforts have been underway to design terminal tackle that reduce severity of injury of hooked fish. Though there are many studies on the injury points and mortality rates of fishes by the use of circle hooks and other hooks in other parts of the world, such studies are lacking in the Indian context. In view of the angling related tourism development promoted in many states of India (Thomas *et al.*, 2007) similar studies are very essential. At many parts of the world circle hooks have been promoted as a promising gear to meet the responsible fishing requirement. Unfortunately, there have been few studies that have investigated the efficacy of circle hooks in the Indian conditions. Hence this study is thought to act as a triggering point for further detailed studies on circle hooks in the Indian context.

8.4. Conclusions

Based on the studies carried out, it can be concluded that the Indian hooks are comparable in terms of fishing efficiency, hooking location and severity of wound to imported hooks. There is no significant difference in hooking pattern of the two types of hooks ($P>0.05$). In the fishing performance study involving circle hook and 'J' hooks, the circle hooks showed significantly lower ($P<0.05$) hooking rate compared to the 'J' hooks. Also, there is a significant difference between circle hooks and 'J' hooks in terms of hooking location ($P<0.05$). More fishes were lip hooked with minor injuries in circle hooks against that of 'J' hooks. This finding is in agreement with the related studies carried out on circle hooks in other parts of the world. This feature of the circle hook makes it an ideal hook type that can be used for 'catch-and-release' (recreational) fisheries.

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Chapter - 9

SUMMARY AND RECOMMENDATIONS

Fishing hooks were in use from time immemorial. Fishing hooks used in the ancient days were made of wood, bones and sea shells. They were later succeeded by copper (Cu) and bronze hooks. The present day fishing hooks are made from high carbon steel wire. Fishing hook is considered as a simple, easy to operate, economically viable and efficient fishing tool. And they form the indispensable part of any hook and line fishing system. Hook and line fishing is considered as a highly selective low energy fishing method and is well suited for the exploitation of sparingly distributed fishes in a sustainable way. Moreover, the fishes captured by hooks and line fishing are of relatively large in size and of better quality. Hook and line fishing is becoming increasingly important in the Indian fisheries also, especially in the harvesting of under exploited tuna resources in the Indian Exclusive Economic Zone (EEZ). Despite their importance in fishing, very few studies have been conducted on fishing hooks. Baranov (1976) and Kenchington and Halliday (1994) have reported that there is a scarcity of research work on the different properties and quality of fishing hooks. Hence this study has been undertaken with the objectives of (i) evaluation of current status of availability and cost of fishing hooks in India, (ii) evaluation of physical and mechanical properties of different types and sizes of hooks, (iii) standardization of the hook numbering system, (iv) correlation of mechanical strength of fishing hooks with the chemical composition, (v) evaluation of corrosion resistance of hooks and probable corrosion protection/prevention measures and (vi) comparative evaluation of fishing performance of hooks.

The content of the thesis is organized into various Chapters and a summary of each chapter is given below:

The first chapter gives a general introduction to fishing hooks, and their importance as fishing tool and related problems. The background of the topic and the significance of the study are highlighted. The importance of hook and line fishing as a low energy fishing method and as a selective fishing gear is brought in this introductory chapter. This chapter also covers the present status of hook and line fishing from the world and Indian perspective. The importance of hook-based fishing methods such as tuna fishing, sport fishing/recreational angling are also discussed. The history of fishing hooks, hook terminology, hook manufacturing process, hook types, their classification and hook numbering systems are explained. The evolution of fishing hooks from the pre-historic ones to the present day metallic hooks is also discussed. Different parts of fishing hooks, their terminology and morphological characteristics are also dealt in detail. The manufacturing process of modern metallic hooks, their classifications based on shape, number of bends, point and barb are also discussed. Different hook numbering systems and their comparison is given. The aim, scope and the objectives of the research work on fishing hooks is also detailed.

The second chapter deals with a detailed review of work carried out by different researchers on the physical, mechanical and chemical properties, corrosion resistance and fishing performance of fishing hooks. Various aspects relating to fishing hooks collected through detailed literature survey are discussed in detail. This review brings out the gaps in the research work on fishing hooks.

The materials and methods followed in this study are detailed in the third chapter. Area of the study, sample collection methods, procedures followed for the measurement of different properties of fishing hooks and sample preparation procedures for different analysis are described. Experimental procedures for the evaluation of mechanical strength, chemical composition, corrosion resistance and fishing performance of the fishing hooks studied are also outlined. Statistical methods followed for the analysis of the data are also given. There were four distinct systematically planned phases in this study. In the first phase, a detailed review of the literature on studies done on fishing hooks was undertaken. In the second phase a preliminary survey was conducted to assess the availability and present status of fishing hooks and their use in India. In third phase, different types and sizes of fishing hooks were collected form different parts of the country, covering all major fishing centres. The fourth and final phase involved analysis of different parameters of the collected hooks in laboratory and evaluation of their performance in actual field.

The current status of availability of different types fishing hooks and their prices in India are detailed in fourth chapter. Selection of sample and data collection centres and methods followed in sample and data collection are dealt in detail. It was found that a large variety of fishing hooks, of varying quality and price, manufactured under different brands, both imported and Indian, and unbranded locally made are available in India. Round bent, Kirby, Limerick, Circle hooks, Tuna hooks and Treble hooks are the major commercial types of fishing hooks available in India. A total of 282 types of hooks of different size/number, coming under 7 imported brands, 7 Indian brands and 4 unbranded Indian hooks were collected as part of this study. The availability of important Indian and imported brands and unbranded indigenous hooks and their prices are discussed. The prices of imported brands of hooks were found to be double that of Indian brands and three fold that of unbranded locally made hooks. A data base developed on the availability and cost of fishing hooks in India as part of this study is presented.

The fifth chapter deals with the results and discussion on the physical and mechanical properties of fishing hooks. Physical and mechanical properties of all the 282 denominations of fishing hooks collected were studied, analysed and catalogued. A data base on the physical and mechanical properties was made as part of this study. No significant variation was observed among different types of hooks tested with respect to dimensional characteristics such as total length, hook wire diameter, gape and bite. However, considerable variability was noticed in their resistance towards unbending viz., deformation equal to bite length. The physical properties and the mechanical strength of fishing hooks show that indigenous fishing hooks are comparable to imported fishing hooks in terms of physical and mechanical properties. Since unbending test results were in conformance with the mechanical strength performance observed in the field, it is concluded that unbending test could be used for the selection of most suitable fishing hook from different types of hooks as per the strength requirements. It was found that there is a highly positive correlation between the hook number and the gape width of hooks (P=0.01). Similarly, there is a positive correlation between the weight and wire diameter of hook with their unbending force. A new standard specification for fishing hooks and a new hook numbering system based on gape width was developed as an outcome of this study.

The studies on chemical composition of fishing hooks are presented in the sixth chapter. Comparison of chemical compositions of indigenous unbranded hooks with that of indigenous and imported branded hooks was carried out. The composition of the hooks of different brands was approximately same with same elemental makeup. The samples contained 0.75 to 0.76 wt. % of carbon (C). The correlation between different elements with the mechanical strength of fishing hook is also analysed and the results are presented. Significantly high positive correlation was found between the carbon content and the unbending resistance of the hooks studied ($r=0.99$, $P<0.05$). Though the chemical constituents of the hooks studied were approximately same, significantly large amounts of lead (Pb) was present in unbranded indigenous samples.

The outcome of the corrosion resistance studies of fishing hooks is discussed in seventh chapter. Corrosion is the most important factor, which affects the service life of fishing hooks. Corrosion of metallic fishing hooks is a perpetual problem as they are operated in highly corrosive environment like the seawater. Results showed that tinned and nickeled hooks (coated with nickel) are superior in corrosion resistance to that of polymer coated hooks. On accelerated corrosion analysis, tinned hooks recorded a mean weight loss of 5%, whereas the blue finished hook (coated with blue coloured polymer) showed significantly high weight loss of 20% by weight ($P<0.05$). Among large sized shark hooks (hook number 1, 'J' style fishing hooks), Indigenous unbranded hooks found to be better in resisting accelerated corrosion tests than imported and Indian branded hooks. It was found that rigging snood wires to the fishing hooks significantly increases the corrosion rate. The corrosion rate of hooks with snood wire was 109.316 mpy and that of hooks without snood wire was 60.21mpy. Treating fishing hooks with Cerium (Ce) was found to resist corrosion at the initial phase of accelerated corrosion tests i.e., the first 100 h of exposure, which is equivalent to about 1 year exposure in sea water. However, its effect is found to be insignificant in resisting corrosion when exposed to 300 h of salt spray. Application of lubricant oil and fish oil was found to be very effective in preventing corrosion in fishing hooks exposed to salt spray.

The fishing performance of different types of hooks is discussed in the eighth chapter. In the first part, hooking rate of imported branded hooks was compared with that of Indian branded hooks. The hooking rates were 14.18% and 12.41% for the imported and Indian hooks respectively. However statistically there was no significant difference in hooking rate of the two types of hooks ($P > 0.05$). The location of hooking and the severity of wound were also studied. World over, circle hooks are being promoted as a responsible fishing gear. But very little information is available on the fishing performance of circle hooks in the Indian context. Considering this, fishing performance evaluation of circle hooks with that of 'J' style hooks was also carried out. Difference in hooking rate, hooking location and severity of wound in circle hook and 'J' hook are discussed. The circle hooks showed significantly lower ($P < 0.05$) hooking rate compared to the "J" hooks. The circle hooks showed a hooking rate of 8.65% while the J-hook had a higher hooking rate of 15.56%. There was a significant difference between circle hooks and 'J' hooks in terms of hooking location ($P < 0.05$). More fishes were lip hooked with minor injuries in circle hooks. This feature of the circle hook makes it an ideal hook type that can be used for catch-and-release (recreational) fisheries.

The salient findings of the study are summarized below:

1. Prepared data base on availability, cost and properties of fishing hooks, of different size specifications available in India.
2. A data base on the physical and mechanical properties of different types of hooks was made which can be used in further studies on fishing hooks.
3. Standard specifications for the different sizes of hooks viz., hook number, gape, hook wire diameter, length of the hook, bite length, weight and unbending load worked out for hooks of different sizes based on the physical and mechanical properties of 282 types of

hooks of different brands, size/number and material that were collected as part of this study.

4. A new system of hook numbering based on gape width was developed incorporating merits of conventional marine numbering system and the Indian Standard specification for fishing hooks.
5. Indian hooks were comparable in their physical and mechanical properties with that of imported costly brands.
6. The unbending test method employed to analyse the mechanical strength of fishing hook in this study was in agreement with the actual performance by the fishing hooks in the field and this test could be effectively used to evaluate mechanical strength of fishing hooks.
7. There was significant positive correlation between the carbon (C) content and the unbending resistance of the hook samples studied.
8. Indigenous hooks were found to be better in resisting corrosion than imported hooks.
9. Tin (Sn) coated hooks were better in resisting corrosion in contrast to blue polymer coated hooks and were more suited for marine applications.
10. Attaching snood wires to the fishing hooks significantly increased the corrosion rate of hooks. The enhancement of corrosion rate of hooks rigged with snood wire was found to be due to the combined effect of bimetallic corrosion and retention of corrosive medium in crevices at the point of attachment.
11. Treating fishing hooks with cerium (Ce), fish oil and lubricant oil were found to be very effective in controlling corrosion.
12. There was no significant difference between Indian hooks and imported hooks in fishing efficiencies, hooking locations and severity of wounds. In experimental fishing study, significantly more number of fishes were lip hooked with minor injuries in circle hooks than in ‘J’ hooks.

In short, it was found that indigenous fishing hooks are comparable with imported hooks in terms of mechanical strength, corrosion resistance and material composition. They fared very well in fishing performance studies also. Results from the present study have implication in the design, fabrication and operation of different types of hook and line gears. This would help in the selection of appropriate hook with required properties. Besides, the results of this study also have other implications like substitution of imported hooks with indigenous hooks, which can save about Rs. 5.83 crores annually in foreign exchange. Results from the present study also have significance in the development of newer hook designs and patterns.

9.1. Scope for further studies

It is evident from the present study that there is a vast scope for further research work on fishing hooks, especially giving emphasis on their physical and mechanical properties, introduction of newer materials, coatings, corrosion resistance in actual field environment, design improvements and fishing performance etc. These studies should take into account the changes in the modern manufacturing methods, materials and products with an objective to facilitate easy selection of the right hook for fishing purposes.

The important suggestions for further studies are listed below:

1. Application of new composite materials and alloys in manufacture of hooks with improved mechanical properties and corrosion resistance can be studied.
2. The effect of corrosion on the tensile strength properties of the hooks can be taken up.

3. A detailed evaluation of the corrosion resistance of hooks in actual field environment can also be further studied with emphasis on suitable corrosion control methods.
4. Studies can be undertaken to prevent/reduce the higher corrosion observed in fishing hooks tied with snood wire. This could be prevented by using non-corrosive rings or non-metallic alternative materials which will avoid/minimize the crevices at the point of attachment and would also avoid the bimetallic corrosion.
5. There is scope for further exploring the effect of lubricant oil and fish oil treatment on corrosion prevention and fish behaviour in the filed condition. It is assumed that there would be certain favorable effect in attracting fish towards the hook when fish oil is used.
6. Large scale fishing performance studies with different sizes and types of fishing hooks in the Indian context can be taken up. Studies to find out optimum hook sizes/gape width for different fish species can also be taken up.
7. Detailed studies on the performance of circle hooks in Indian waters needs to be taken up focusing on their ability to reduce gut hooking and by-catch. Their use in catch-and-release (recreational) fisheries needs to be further explored. Such studies would aid the decision makers in implementation of regulations related to fish welfare and sustainability.

9.2. Recommendations

Based on the present study the following recommendations are put forwarded:

- Indigenous branded and un branded hooks may be promoted against the costly imported hooks without compromising on performance.

- The standard specifications worked out for fishing hooks may be implemented for uniformity in quality of hooks produced by different manufacturers. Competent authority may be authorized to monitor the quality standards of fishing hooks sold in the market.
- The new hook numbering system may be adopted which gives more sensible idea about the size and properties of a hook.
- Tinned hooks may be preferably used in marine conditions owing to their better salt tolerance than the blued hooks.
- More emphasis should be given to corrosion control measures when metallic snood wires are tied to fishing hooks.
- Simple measures like treatment with cerium (Ce), application of fish oil and lubricant oil may be used for effective control of corrosion in hooks.
- In recreational angling or catch-and-release fishing (sport fishing) fast corroding fishing hooks may be promoted over corrosion resistant fishing hooks. A fast corroding hook will improve the survival rate of released fish in those cases (When a fish is ‘deep hooked’ where it is very difficult to remove the hook without seriously injuring the fish) wherein the fish has to be released with the hook inside the body.
- Use of circle hooks may be promoted in Indian waters to reduce severe injury to the fishes caught, especially in ‘catch-and-release’ recreational fisheries.

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Appendix - 1

LIST OF PUBLICATIONS

A) Related Publications:

1. **Edappazham, G.**, Thomas, S.N., Meenakumari, B. and Ashraf, P. M. (2008) Physical and mechanical properties of fishing hooks, *Materials Letters,* 62:1543–1546. (DOI:10.1016/j.matlet.2007.09.019.).
   (Impact Factor: 1.748, *Journal Citation Reports®, 2009).

2. Thomas, S.N., **Edappazham, G.**, Meenakumari, B. and Ashraf, P. M. (2007) Fishing Hooks: A Review, *Fishery Technology*, 44(1) pp:1-16.

3. **Edappazham, G.**, Thomas, S.N. and Ashraf, P. M. (2007) Effect of snood wire on corrosion rate of fishing hooks. Paper presented in the 8th Asian Fisheries Forum (8th AFF 2007), held at Cochin during 20-23 Nov 2007.

4. **Edappazham, G.**, Thomas, S.N. and Ashraf, P. M., (2010) Corrosion resistance of fishing hook with different surface coatings, *Fishery Technology* (Accepted for publication).

B) Others:

5. **Edappazham, G.**, Thomas, S.N., Meenakumari, B. and Ashraf, P. M. (2006) Use of Fishing Sinkers along Kerala and Tamil Nadu Coasts In. *Sustain Fish*, B.M. Kurup and K. Ravindran (Eds.), School of Industrial Fisheries, Cochin University of Science and Technology, Cochin-682016, India. pp. 482-495.

6. Thomas, S.N., John B., **Edappazham, G.**, Kalidas, C. and Meenakumari, B. (2009) Standardization of polyamide monofilament yarns for fabrication of gillnets with reference to physical and mechanical properties, *J. Mar. Biol. Ass. India*, 51 (1).

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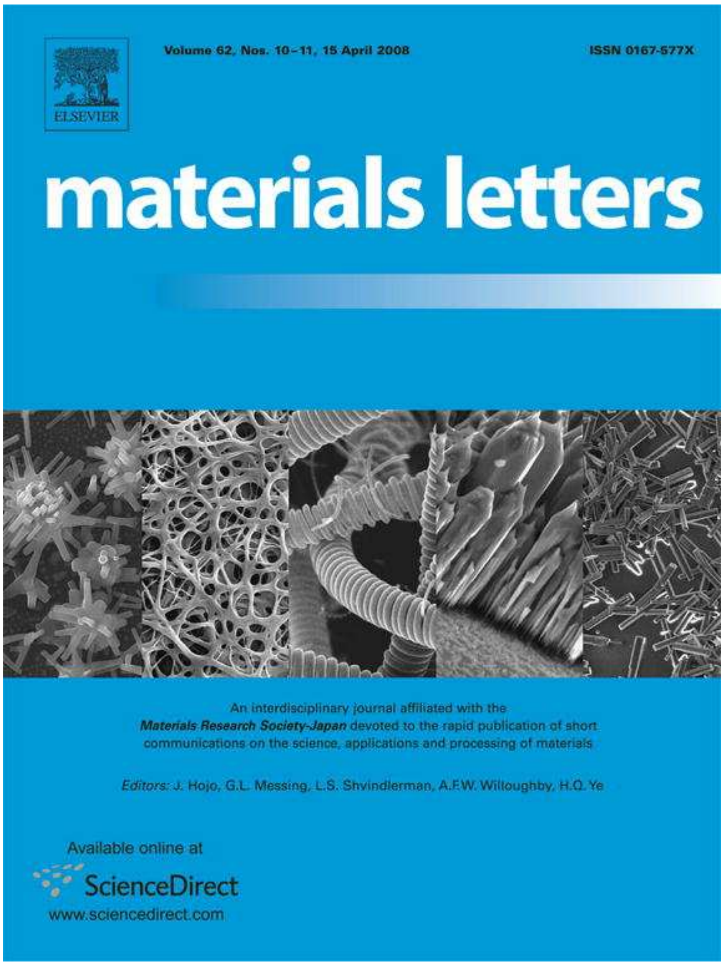
Appendix - II

REPRINT OF IMPORTANT PUBLICATION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Physical and mechanical properties of fishing hooks

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Abstract

Very few studies have been conducted to analyse physical and mechanical properties of fishing hooks. The present work is an account of a study carried out on five major brands of number seven round bent fishing hooks available in India, which are used to harvest tuna and medium sized fish resources. We have selected three imported and two indigenous brands of fishing hooks. The dimensional characteristics and unbending force as tensile load for deformation of the hook bend equal to its bite length were investigated. The mechanical strengths of the fishing hooks studied were highly varied and brand IB-1 recorded the highest unbending force of 275.9 N. It was found that the unbending test method employed to analyse the mechanical strength of fishing hook in this study is in agreement with the actual performance by the fishing hooks in the field and this test could be effectively used to evaluate mechanical strength of fishing hooks.

Keywords: Mechanical properties; Fishing hooks; Metals and alloys; Unbending test; Deformation; High carbon steel

1. Introduction

Hook and line fishing is a highly selective low energy fishing method and is well suited for the exploitation of sparingly distributed fishes. It is one of the most ancient fishing techniques, which is still in use all over the world [1]. Fishing hooks form the indispensable part of any hook and line fishing system. Modern day fishing hooks are manufactured from high carbon steel wire [2,3]. The characteristic bend of fishing hook is formed by physically bending the wire to the desired shape and style. The most important step in hook manufacture is the tempering of the hook in which the hook is hardened to improve strength. This process hardens the metal and substantially increases its resistance to unbending, resulting in strong hooks with reduced brittleness. The resistance of fishing hooks towards unbending force is a very essential property as far as fishing hooks are concerned. But we have found that references of such studies are very limited. Most studies carried out were focused towards fishing efficiency of different fishing hooks [4–6].

Properties like hook shape, hook size and mechanical strength of the hook bend have a direct influence on the fishing performance of the hook. The fishing hooks available to the fishermen are not uniform in their physical and mechanical properties and a high degree of variation is seen between different brands. These variations could be attributed to difference in the steel wire used for manufacture of hooks and differences in hook manufacturing process [2,3]. Kitano et al. [7] studied the corrosion resistance of tuna long line fishing hooks. Ko and Kim [8] tested six types of fishing hooks for breaking and unbending due to plastic deformation of the material using dynamometer. They have also studied the dynamic forces acting on the fishing hook during hooking and hauling. Varghese et al. [9] studied the physical properties as well as corrosion resistance of fishing hooks from five indigenous hook manufacturing firms and that of one imported brand. It is difficult to compare between different brands of fishing hooks and there are no standard methods available to test the mechanical strength of fishing hook. Often fishermen have to depend on their experience while selecting a fishing hook. So a comparative study of these hooks would help the fishermen in selecting fishing hooks with better mechanical properties and performance. Here an attempt is made to compare the physical and mechanical properties of five different types of fishing hooks.

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2. Experimental

Number seven size round bent fishing hook was selected for the comparative study, as it is commonly used by the fishermen for catching fishes like tuna and medium sized fishes. These are three imported brands, coded as FB-1, FB-2 and FB-3 and two indigenous brands, coded as IB-1 and IB-2. The physical dimensions of the hooks were measured as per IS: 9860 (Part I) — 1981 [10]. The general terminology used in fishing hook and different parts of a typical fishing hook is given in Fig. 1. The various parts of a typical fishing hook are eye, shank, bend, gape, bite, point and barb.

Wire diameter measurement of fishing hook was taken on the round unforged portion of the shank using a micrometer (Mitutoyo, $d = 0.01$ mm). Microstructural observations of the samples were made after polishing and etching with 5% nital solution (using 'Leica MZ16 A' light microscope). Unbending resistance of fishing hook was taken as a measure of mechanical strength in their functional form. Unbending test is a modified form of conventional tensile test wherein the force required by the hook bend to develop a deformation equal to its bite length was measured using Shimadzu AG-I 10 kN Universal Testing Machine (UTM), with a cross head speed of 25 mm/min as per Varghese et al. [9] (Fig. 2). This test gives a measure of the force a hook bend can withstand. The deformation of hook bend equal to bite length was taken as the standard as any deformation beyond this point will render it useless for fishing. The results of the unbending test were verified with the feed back taken from fishermen about the mechanical performance of fishing hooks under use.

3. Results and discussion

Chemical composition and physical properties of studied fishing hooks are given in Table 1. No significant variation was observed among the five types of hooks studied with respect to total length, hook wire diameter, gape and bite (Table 1 and Fig. 3). However, significant variation was noticed in their unbending force.

All the five types of hooks had almost uniform hook wire diameters and variation was insignificant. The unbending force of the five types of hook is shown in Fig. 3. Out of the five types of hooks, the indigenous brand IB-1 recorded the highest unbending force, 275.9 N while IB-2 recorded the least (Fig. 3). On statistical analysis, brand FB-1 is found to be significantly different from brands FB-2 and IB-2 in terms of unbending force. Similarly brand FB-2 is significantly different from FB-3 and IB-1, brand FB-3 is significantly different from IB-2 and brand IB-1 is significantly different from IB-2. It was found that the unbending force of fishing hooks is positively correlated with their wire diameter (Fig. 3).

The fishing hooks were classified as 'excellent', 'good' and 'poor' with regards to their mechanical strength based on the feed back collected from fishermen who are using these hooks. According to this, brands FB-1 and IB-1 were excellent, brands FB-2 and FB-3 were good and brand IB-2 was poor in their mechanical performance in the field. This is in agreement with the unbending test results with exception of FB-2 which showed poor mechanical strength in unbending test.

The deviations in mechanical strength among the five types of fishing hooks studied could be due to the different material compositions and heat treatment given during manufacturing process. In light microscopy we found that the hooks with high mechanical strength had a uniform fine grain-sized microstructure when compared to IB-2 (Fig. 4). Mechanical strength of a fishing hook bend is very critical for successful fishing. This is more important in the hook and line fishing of large fast moving fishes like tuna. These fishes will transfer lot of kinetic energy to the fishing hook while hooking and this could lead to hook failure, which ultimately results in loss of the catch. Varghese et al. [9] carried out the unbending test of fishing hooks by recording the load required for deformation of the hook bend. Varghese et al. [9] reported that indigenous fishing hooks were fragile and could be easily deformed under load when compared to imported brands of

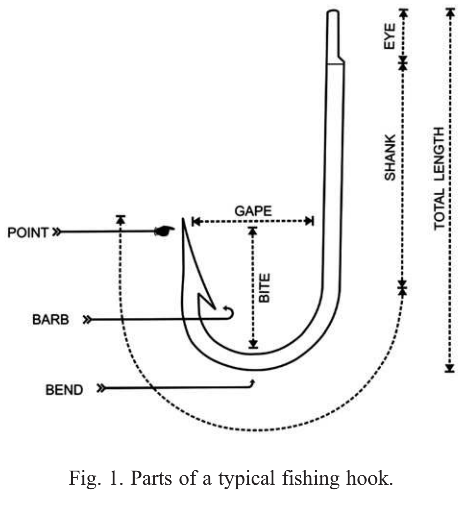

Fig. 1. Parts of a typical fishing hook.

Fig. 2. Unbending test of fishing hook using UTM.

Table 1
Chemical composition and physical properties of fishing hooks investigated

	FB-1	FB-2	FB-3	IB-1	IB-2
Chemical composition (wt.%)					
Manganese (Mn)	0.51	0.62	0.64	0.76	0.65
Nickel (Ni)	0.02	0.04	0.06	0.01	0.01
Copper (Cu)	0.01	0.08	0.07	0.03	0.02
Chromium (Cr)	0.02	0.02	0.04	0.10	0.01
Carbon (C)	0.57	0.76	0.69	0.83	0.76
Physical properties					
Total length (mm)	41.70	40.00	39.00	39.50	40.30
Gape (mm)	15.00	15.90	15.40	15.10	15.10
Bite (mm)	16.90	17.50	17.30	17.00	16.10

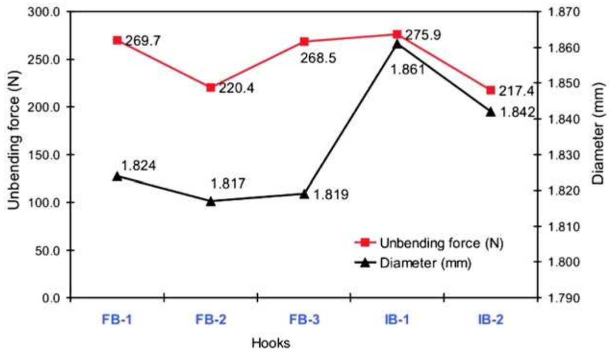

Fig. 3. Unbending force and wire diameter of fishing hooks investigated.

fishing hooks. But the present study indicates that indigenous brands are equally good in mechanical strength.

The imported brands of fishing hooks are costly, compared to the indigenous brands of the same size. However, fishermen are more inclined towards the imported brands, apparently due to the brand loyalty acquired over the years, much before the indigenous brands came into the market. It is clear from the study that indigenous brands are comparable with imported brands of fishing hooks with respect to their physical and mechanical properties. Since unbending test results were in conformance with the mechanical strength performance observed in the field, unbending test could be used for the selection of most suitable fishing hook from different types of hooks as per the requirements.

4. Conclusions

After analysing the physical and mechanical properties of the five types of fishing hooks, we have made the following conclusions:

(1) Unbending test could be used as an effective tool in analysing the mechanical properties of fishing hooks.

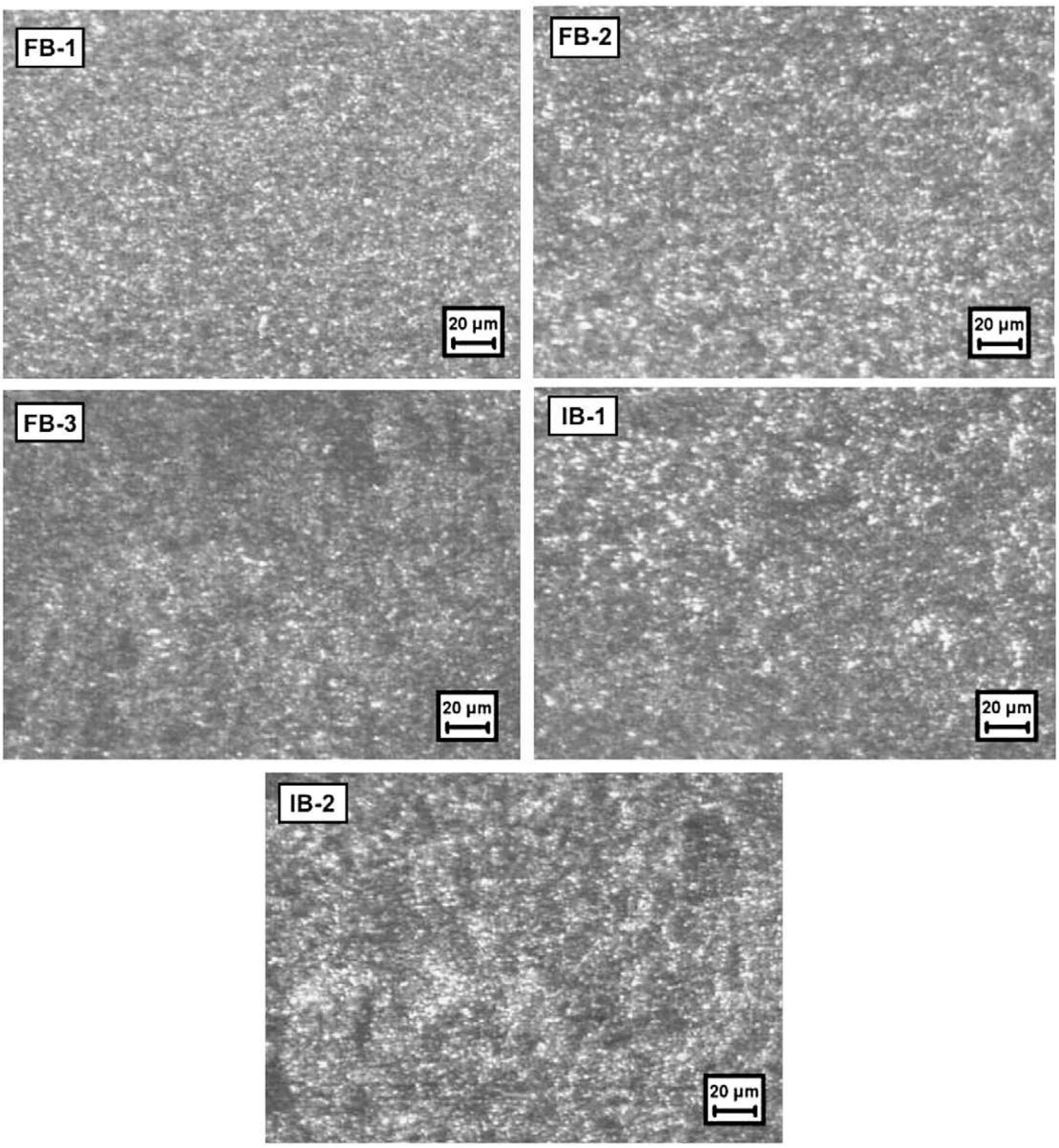

Fig. 4. Microstructure of studied fishing hooks etched with 5% nital.

(2) In unbending resistance, the indigenous brand IB-1 is found to be comparable with the imported brands FB-1 and FB-3. Moreover, IB-1 showed higher unbending resistance than brands IB-2 and FB-2.
(3) The wire diameter and the unbending force of fishing hooks are positively correlated.

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