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CHEMICAL AND PHYSICAL PROPERTIES OF SYNTHETIC FIBRES MOST COMMONLY USED IN FISHING GEAR, WITH REFERENCE TO THEIR USE IN CAPE VERDE FISHERIES

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ABSTRACT

This study deals with the following synthetic fibres: Polyamides, Polyesters, Polyethylene, Polypropylene, and Dyneema. The objective was to identify the characteristics of each of them and give basic information about these fibres with reference to their use in Cape Verde fisheries. A series of experiments was carried out about breaking strength, elongation, elasticity, resistance to abrasion and weathering, properties that are of a great importance in ensuring correct performance of a particular gear. Dyneema is the newest fibre and special attention was given to it in this study. Also the selection of synthetic materials is discussed.

Key words: polyamide, polyethylene, polypropylene, polyester, Dyneema, Cape Verde.

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1 INTRODUCTION

The oceans, seas and other water cover more than 70% of the earth's surface. They occupy about 90 million sq. miles and yield approximately 80 million tons of fish annually (FAO 1996).

Fishing is one of the oldest professions of man. Fisheries have developed continuously over the centuries, utilising improved and larger ships, more sophisticated fishing equipment and catch preservation techniques.

Modern fishing has developed through three main technological revolutions (Sainsbury 1996).

- Mechanisation begins in the second half of the nineteenth century with the use of steam driven capstans. Steam power was successfully used in towing a trawl for the first time in 1877 and from that time steam gradually replaced manual and sail propulsion before being superseded by the internal combustion engine. Today, the engine is universally favoured for larger vessels while petrol driven outboards remain common for small boats.
- Introduction of electronic fish finding equipment started half a century ago. Aircraft enable large areas to be searched visually, while satellite and laser technology are being utilised as aids to identify suitable environmental conditions and in finding fish schools. Recent developments in microprocessor technology enable rapid analysis of signals from high performance transducers. Today microprocessor technology also permits electronic navigation, fish detection, ship handling and fishing gear control to be integrated and fishing operations to be increasingly automated.
- The advent of synthetic fibres heralded the third major revolution in modern fishing gear. Until recently, natural fibres such as sisal, manila and cotton were by far the most important raw materials for ropes and nets, and only during the last two or three decades have they been gradually replaced by synthetic fibres. Synthetic fibres are man-made from fibres, which have been produced entirely by chemical synthesis from simple basic substances. As compared with vegetable fibres they are of better uniformity and continuity, have higher breaking strength and are more resistant to rotting. These materials have greatly extended the endurance of gear, and together with the mechanised net and rope making have increased the size and complexity of nets.

The development of synthetic fibres started around 1920 by Staudinger, winner of the Nobel Prize in chemistry in 1953 (Klust 1982). Staudinger found that all fibrous material consists of long chain molecules in which a great number of equal, simple units are linked together. This structure gives the fibrous material the properties required from a textile fibre. Based on this knowledge, a great deal of other chemical research has been carried out in recent years to create such fibre-forming macromolecules. At the present many groups of synthetics fibres are produced for the fishing industry (Appendix 1). The most important countries manufacturing man-made fibres are USA, Japan, Netherlands, Great Britain and France.

Developments of new synthetic materials and fabrication techniques play an important role in improving fishing gear efficiency. However, as different classes of synthetic fibres become available, the fishermen's and the netmaker's knowledge of the different materials and their characteristics is often not good enough to allow optimum selection and utilisation (principally in the developing countries).

The objective of this project is to compare the general characteristics of the synthetic fibres most commonly used in fishing gear (polyamide, polyester, polyethylene, polypropylene, polyvinyl and dyneema) and to provide essential information on their properties, with reference to their uses and application in Cape Verde fisheries. Dyneema is the newest of these fibres and will be given special attention in this study.

1.1 Cape Verde Islands and their fisheries

The Archipelago of Cape Verde is located 450 km off the coast of Senegal, West Africa, and is composed of 10 islands and 8 islets. The islands are of volcanic origin and positioned between 15° and 17° N. The islands are divided into two groups named according to the trade winds that reach them from the African continent: windward and leeward. The first group consists of the islands of Santo Antao, Santa Luzia, São Nicolau, Sal and Boavista. The second group more to the south, comprises the islands of Maio, Santiago, Fogo and Brava.
With a total of 4,033 km^2, Cape Verde is one of the five Atlantic archipelagos of the Macronesia. The others are Azores, Madeira, The Canary Islands and Savage Isles.

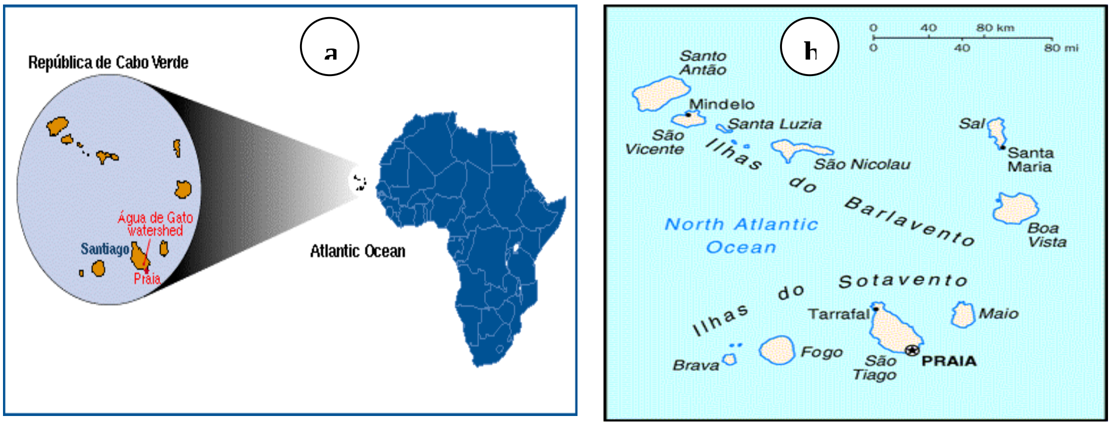


Figure 1: The archipelago of Cape Verde (Cape Verde - visiting card 1999)

The fisheries sector contributes about 5% to the GNP of Cape Verde. It is important for the local economy and employs over 7000 fishermen and 3200 fish traders (INDP 1996).
Fish is an important source of nutrition to the population and constitutes 70-90% of animal protein in the diet. Consumption of fish and fisheries products is 18,5 kg/year per capita (FAO 1996). The fisheries potential in Cape Verde waters is estimated at around 30.000 - 35.000 tons but only 26% of this potential is exploited. The total catch in 1997 was 9160 tons (INDP 1996). In general the fisheries can be divided into industrial and artisanal fisheries. The industrial fleet (>11 m) is composed of 32 small vessels <20 tons GRT each, mainly catching pelagic species such as tuna and horse mackerel. The artisanal fleet is composed of 1455 small vessels locally called "botes" (towing boats with outboard engines), catching tuna, small pelagic and demersal species. Industrial fishermen use mainly hand-lines, purse seines, and traps and artisanal fishermen use hand-lines, small purse seines and beach seines.
Most fishermen in Cape Verde, lack formal training. The knowledge they possess is gained from experience or learned from their fathers. So fishing gear is constructed in an empirical manner without consideration for the quality of the materials to be used in the construction process.
The principal synthetic materials used in Capverdian fishing gear are listed in Table 1.

Table 1: Principal synthetic materials use in Capverdian fishing gear

	Materials	
Gear	Type	Specification
Purse seine (small pelagic and mackerel)	Netting	PA.R.155 tex 24mm, PA R 230 tex 24 mm, PA.R.310 tex 24 mm, PA.R.310tex 20 mm, PA.R. 860 tex 120 mm, PA.R.310 tex 16 mm, PA.R. 230 tex 16 mm, PA.R.620 tex 100 mm
	Ropes	PA 8, 10, 16 mm, PE 16 mm
Beach seine	Netting	PA.R.310 tex 50 mm, PA.R. 310 tex 30 mm, PA.R.310 tex 24 mm, PA.R. 390 tex 20 mm, PA.R.390 tex 16 mm
	Ropes	PA 10, 12mm, PE 14 mm
Gill net	Netting	PA mono 60 mm ø 0.30 mm, PA 160 mm R 950 tex, PA 60 mm R 230 tex PA 6 , 10, 16 mm, PE 8 mm, PP 3
Traps	Ropes	PES 22 mm

Most of these materials are imported from Portugal by the National Institute of Fishing Development (INDP) which stipulates the price. INDP has commercial centres distributed in fishing communities all over the country. The Institute doesn't pay tax on imported materials and therefore it is difficult for private companies to compete with them. In addition, the materials are limited and their quality is variable. To keep up with developments, new knowledge in fishing industry is important for Cape Verde. The better Capverdian fishermen understand the properties of the various fibres, the better they will be able to employ them in the most useful and appropriate way. The knowledge gained in this study will be used in the training of fishermen and netmakers with the objective of improving fishing gear in Cape Verde. This study will also provide information of interest to entrepreneurs.

2 CHARACTERISTICS OF SYNTHETIC MATERIALS

2.1 Chemical Classification of synthetic fibres

The chemical groups or classes of synthetic fibres that are used in fishing gear are listed in Table 2.

Table 2: Chemical groups or classes of synthetic fibres.

Group	Symbol	Some trade names
Polyamide	PA	Nylon, Amilan, Anzalon, Enkalon, Kapron, Perlon
Polyester	PES	Terylene, Dacron, Diolen, tergal, Terital, terlenka, Tetoron
Polyethylene	PE	Corfiplaste, Courlene, Drylene, Etylon, Kanelight,Nymplex, Polythene
Polypropylene	PP	Meraclon, Courlene PY, Danaflex, Hostalen P, Nufil, Ulstron

Polyvinyl Alcohol	PVAA	Cremona, kuralon, Kuremona, Manryo, Vinylon.
Dyneema[1]	SK 60, SK 75	Dyneema SK 60, Dyeema SK 75, Dynex[2]

1. Polyamide (PA) - hvort er PA 66 eða 6.6?
Several types of PA fibres are manufactured, differing in their chemical components. The most important types are PA 66 and PA 6. PA 66 is manufactured from two components, hexamethylenediamine and adipic acid, each containing six carbon atoms. The PA 6.6 was discovered in 1933 by W.H. Carothers in the USA and is called nylon (Rhodia-polyamide 1999). PA 6 is made from one monomer called caprolactam, which contains six carbon atoms and was first synthesised in 1938 by P. Slack (Klust 1982).
With regard to the fisheries there is no difference between PA 6.6 and PA 6. They are both manufactured in the same manner, and are equally suitable for fishing gear. Therefore, no distinction will be made between the two PA types when discussing the properties of netting yarn in this paper.

2. Polyester (PES)
The principal PES fibres are made from polyethylene terepthalate, and were first synthesised by Whinfield and Dickson in the laboratories of the Calico Printers Association in Great Britain (Kristjonsson 1959). Mr. Whinfield named the fibre "Terylene" .

3. Polyethylene (PE)
PE fibres, used for fishing gear, are produced by a method developed by a German, Ziegler, in the early 1950s. The monomer ethylene, the basic substance of polyethylene, is normally obtained by cracking petroleum. The same applies to propylene, the basic substance for producing polypropylene (Klust 1982).

4. Polypropylene (PP)
Natta, winner of the Nobel Prize in chemistry, developed the synthesis of polypropylene in 1954 (Kristjonsson 1959). PP and PE are often collectively called "polyolefines". Here they are seperated into two groups because of their different properties with regard to fishing nets.

5. Polyvinyl Alcohol (PVA)
PVA fibres, whose production is based on the research of Hermann and Haehnel, have been greatly improved in Japan since 1938 (Klust 1982). It was also the first synthetic material to be used for fishing gear and the first to demonstrate the immense practical advantages of rot-free fibres.
Today their use is very limited in fishing gears, so these fibres have not been included in the present study.

6. Dyneema

[1] Dyneema is a registered trademark of DSM
[2] Dynex is a trademark of Hampidjan

Dyneema fibres are produced by gel spinning, a process invented and patented by the Du Point company (DSM) in 1979 (Swiniarski 1995) and they have been in commercial production since 1990 at a plant in the Netherlands.
" Polyethylene with an ultra high molecular weight (UHMWPE) is used as the starting material. In normal polyethylene the molecules are not orientated and are easily torn apart. In the gel spinning process the molecules are dissolved in a solvent and spun through a spinneret. In the solution the molecules that form clusters in the solid state become disentangled and remain in that state after the solution is cooled to give filaments. As the fiber is drawn, a very high level of macromolecular orientation is attained resulting in a fiber with a very high tenacity and modulus "(DSM 1996).
Dyneema fibres are produced in the following commercial grades:

- Dyneema Sk60 / Sk75 are the multi-purpose grades. These are used for ropes, fishing nets, cordage and protective clothes.
- Dyneema Sk 75 has a higher tenacity than Dyneema Sk 60. This grade is specially designed for ropes, cordage, fisheries and textile applications.

2.2 Identification of synthetic materials

Various kinds of synthetic fibres are similar in appearance. However simple methods can be used to identify synthetic materials. The methods most commonly used by fishermen are:

- The water test, which classifies the netting material according to whether it floats or sinks,
- Burning. The material is identified from the smell of the smoke and the residue.

In Appendix 2 the characteristics of the different synthetic fibres according to the water and burning tests are given.

3 MATERIAL AND METHODS

3.1 Material

In the implementation of this project, tests on physical and chemical properties of PA, PE, PES, PP, Dyneema Sk 60 and Dyneema Sk 75 were to indentify the characteristics of each of them.
The following properties, relevant for their use in the fishing industry, were examined: Breaking strength, elongation, elasticity, resistance to abrasion, strength, density and the changes of length in water.
The tests were conducted from 25 October to 17 November 1999 at Hampidjan, which is a leading manufacturer of high-quality trawls, trawl netting, ropes and others products for deep-sea fisheries. This company has a long history in fishing gear production, dating back to its foundation in 1934.
The samples were collected from materials readily available in the Icelandic market. In the tests for breaking strength, elongation, elasticity and resistance to abrasion, 14 mm, three strand ropes were used. Dyneema ropes are not available in three strand so only the diameter was considered. The choice of the diameter was based on its popularity among fishermen, availability in the market and the capacity of the

available equipment in Hampidjan laboratories. Some characteristics of the material used in the tests are show in Table 3.

Table 3: Material used in the tests for breaking strength, elongation, elasticity, and resistance to abrasion (g/m⇒ gram/meter, denier⇒ Weight of 9000 m).

	Materials				
Characteristics	PA	PE	PES	PP	Dyneema
Weight g/m	104.5	97.8	157	81.2	137.5
Weight denier	938	880	1413	731	1237.5

To measure length changes in water, 1, 1.5, 2.0, 2.5, 3.0, 3.5, 4 and 4.5 mm netting was used. Methods recommended by ISO (International Organisation of Standardisation) were used in most of the tests. The standard temperature and atmospheric pressure for testing is specified for physical tests of textile materials in dry conditions. This requires a relative humidity of 65% and a temperature of 20°C **(**ISO 1973). The Hampidjan laboratory complies with the temperature requirements. Humidity was not measured but variation in humidity in Iceland is small and did not cause any problems during the testing period. All tests were repeated ten times. The results were recorded on data sheets.

3.2 Tests for breaking strength

Breaking strength is the maximum load (force) needed for the material to break. Breaking strength was determined by using a special tensile testing machine made by Koyo Ltd - Japan. It is equipped with one electronic force meter. This machine can apply force up to 20 tons (Fig. 2). The sample is fastened to the clamp of the machine and extended under increasing force until the sample breaks. The electronic force meter registers the force in kilo Newtons needed to break the sample.

1 kilogram-force (kgf) = 9.81 Newtons (N)
1 deca Newton (daN) = 1.02 kilogram-force (kgf)

Sample with two eye splices, one at each end**.**

Figure 2: Tensile testing machine in the Hampidjan laboratory, used to measure breaking strength.

3.3 Free breaking length or strength

Free breaking length or strength is the theoretical length of a fibre, yarn or rope when it breaks under its own weight, when hanging freely. Amount of strength can be calculated by the formula:

$$\text{Strength (g/ den)} = \frac{\text{Breaking strength (Kg)}}{\text{Weight of material in denier}}$$

3.4 Tests for elongation

Elongation is the increase in length of a specimen during a tensile test.

Due the limitation of time and facilities (equipment), only the elongation obtained immediately after the application of a specific tension was observed. A tensile testing machine (Fig 2) was used to determine elongation. Samples of the same dimensions and characteristics as those used in the tests for breaking strength were fastened to the clamps of the machine and submitted to a pre-tension of 100 kN. The length between the two eye splices was measured and specimen was stressed to 75% of its breaking strength and the length measured again. The length increase is the elongation.

Elongation is expressed as % increase of the initial length of the specimen.

$$\text{Elongation(\%)} = \frac{\text{Increase in length}}{\text{Original length}} \times 100$$

3.5 Tests for elasticity

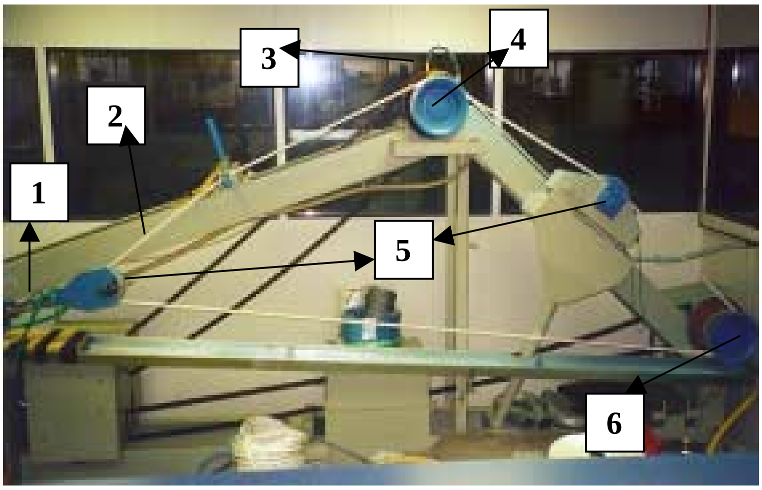
Elasticity is the ability of material to return its original shape and dimension upon cessation of a deforming force.

After finishing the tests for elongation, the force (75% of the breaking strength) was released and the sample submitted again to a pre-tension of 100 kN. The distance between the two eye splices was measured and this measurement is called elastic elongation.
The degree of elasticity is presented as the % decrease in total elongation and is calculated according to the formula:

$$\text{Degree of elasticity (\%)} = \frac{\text{Elastic elongation x100}}{\text{Total elongation}}$$

3.6 Tests for abrasion resistance

Abrasion resistance is the resistance of a material or specimen against wear when rubbed against a surface. This property is important for gear, which operates at the bottom and suffers wear and tear during towing.
Quantitative measurements of wear and tear of fishing materials on board boats is very difficult. Therefore, the situation needs to be simulated in a laboratory. There are many methods of simulation but Hampidjan has developed an apparatus that approaches the "real situation" well. This apparatus consists of four pulleys of different sizes (two mechanically driven pulleys and two others, indirectly driven with the help of the first two). The pulleys are used to adjust the required abrasion speed and pressure on the specimen during testing and a small tap for frequently spraying the specimen with water (Figure 3).



1. Apparatus to exert tension in the sample
2. Sample
3. Tap
4. Mechanically driven pulley
5. Simple pulleys
6. Mechanically driven pulley

Figure 3: Apparatus for testing abrasion resistance in the Hampidjan laboratories.

The sample is tested by putting it into contact with the abrasive surfaces of pulleys of the testing apparatus for 8 hours. Abrasion is measured as the loss of breaking strength.
The results are expressed in % decrease of initial breaking strength.

3.7 Length changes in water

The length change in water was determined with an apparatus closely resembling the one illustrated in Fig. 4 and built with help of Mr. Larus Palmason, Director of fishing department in Sudurnesja Comprehensive College (Keflavik) and supervisor in this project.
The tests were carried out on netting yarn, continuous filament 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4 and 4.5 mm in diameter. According to ISO recommendation, the tests were conducted under dry conditions (standard atmosphere) and the length measurements were carried out under a pre-tension on the specimens corresponding to the mass of 250 m of the respective netting yarn (ISO 1974).
The netting yarn sample of about 100 cm was first measured dry, then again after being soaked in water for one hour.

The results are expressed in % increase or decrease of the initial length of the specimens.

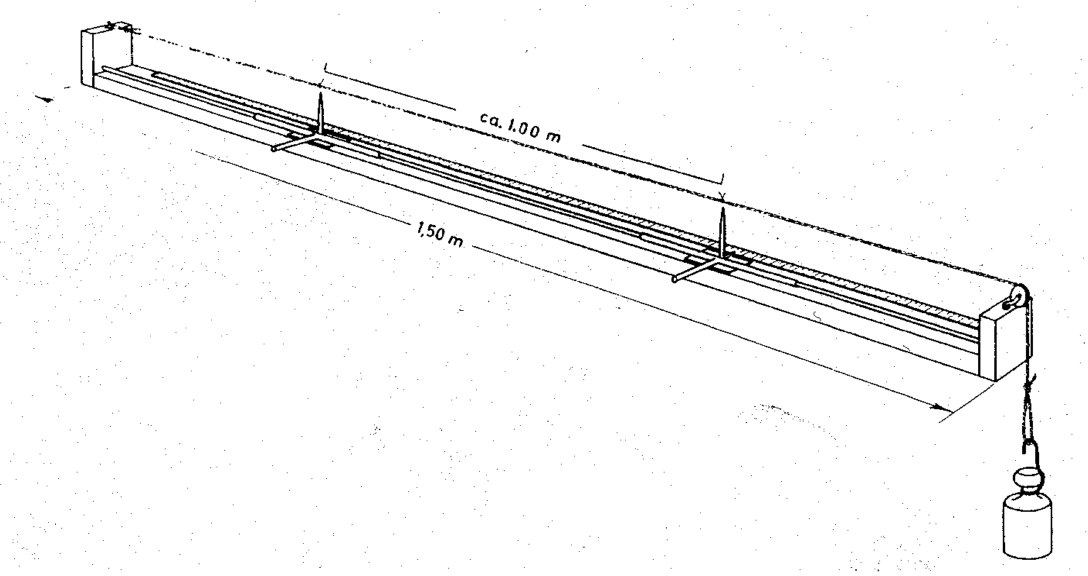


Figure 4 - Apparatus for measuring the length of netting yarn (ISO 1974)

4 RESULTS

4.1 Breaking strength

Figure 5 shows the average recorded breaking strength of ropes, 14 mm in diameter, based on 10 observations. The lowest average observed was for PE (23.4 kN) and the highest was for Dyneema (221.3 kN). Difference in average breaking strength between the PA, PES and PP were not significant. Dyneema was significantly stronger than any of the other materials and PE significantly weaker (Appendix 3).

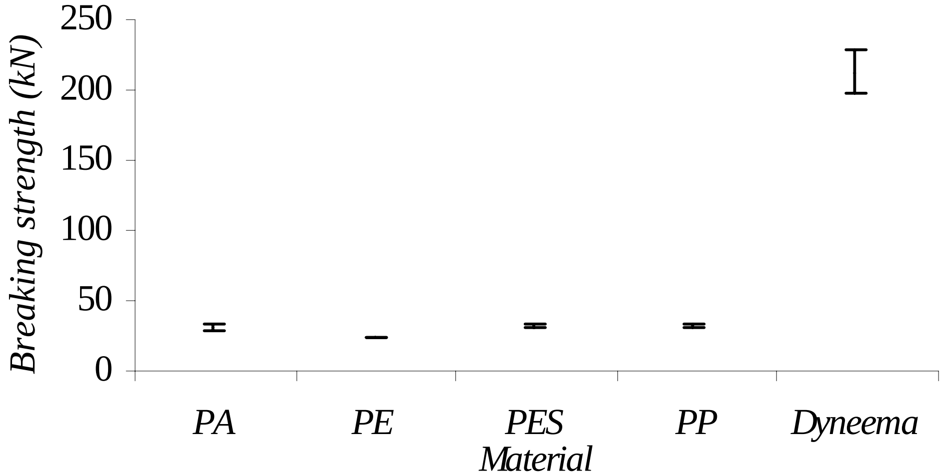


Figure 5: Average breaking strength of 14 mm ropes of different materials based on 10 tests.

4.2 Free breaking strength or strength

The calculated values of free breaking strength, based on breaking strength and the density of material are presented in table 4. Dyneema is in a class of its own, but the order of the other materials is different from the one obtained in the tests of breaking strength.

Table 4: Calculated values of free breaking length for ropes with 14 mm of diameter

Material	PA	PE	PES	PP	Dyneema
Strength (g/den)	3.41	2.72	2.36	4.49	17.49

4.3 Elongation

The results of the elongation tests are presented in figure 6, and the statistical analysis in Appendix 4b.
The differences in elongation between PA, PE, PES, PP and Dyneema were highly significant (F=180.6, $P< 0.05$, F crit = 2.57) and according to pair-wise t-tests, all of them were significantly different from one another (Appendix 4b). Dyneema changed its shape least under pressure while PA stretched the most.
Fig 6: Elongation of 14 mm ropes. The bars are the standard deviation of the means. All the specimens strained by a load corresponding to 75 % of respective breaking strength.

4.4 Elasticity

The elasticity of 14 mm ropes of different kinds of synthetic material were tested in dry conditions is shown in figure 7. The values are presented as a % decrease in total elongation. Dyneema had the highest average elasticity and PP the lowest.

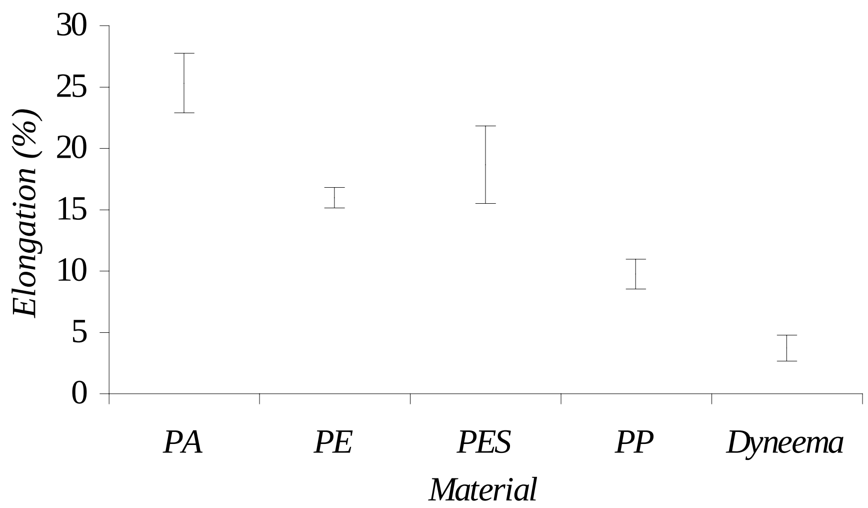


Figure 7: Elasticity of 14 mm ropes. The bars are the standard deviation of the means.

The difference in elasticity between PA, PE, PES, PP and Dyneema was significant (F = 3.20, P=0,02, F=2.58)(Appendix 5).

4.5 Resistance to abrasion

Figure 8 shows the average initial breaking strength in comparison to the breaking strength after the material had been submitted to 8 hours of abrasion. All materials lost same strength during the tests. In relative terms, the loss of strength was least in Dyneema and most in PP (Fig. 9).

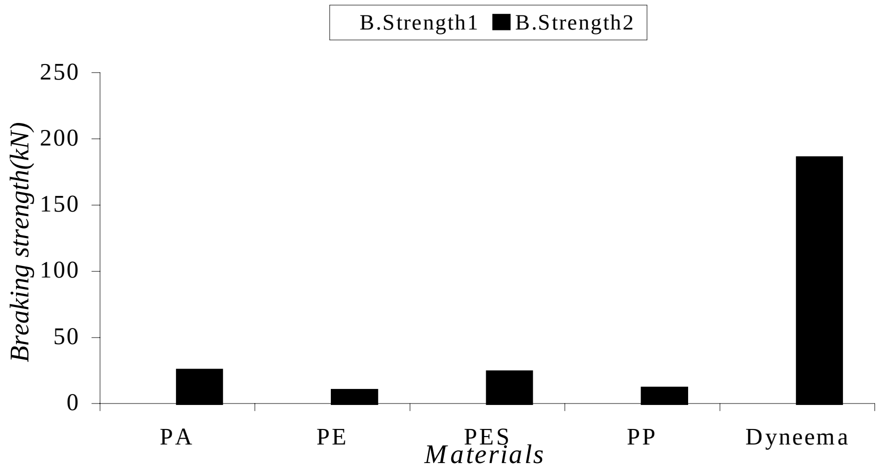


Figure 8: Comparison of original breaking strength and the breaking strength after 8 hours of abrasion.

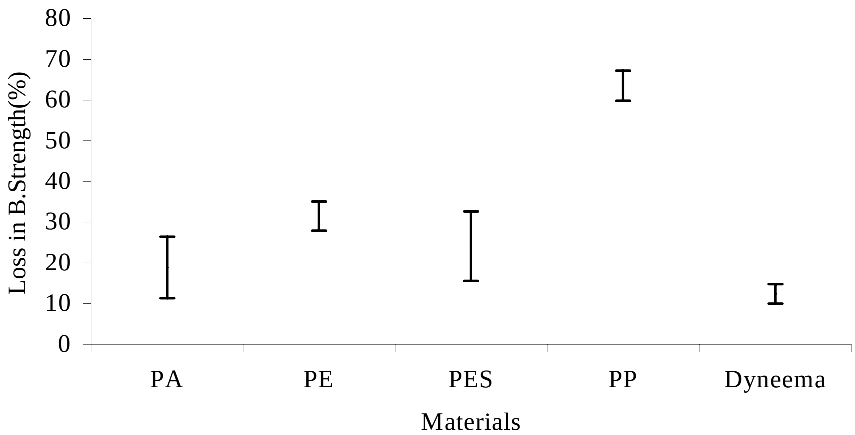


Figure 9: Loss in breaking strength after materials being submitting to abrasion for 8 hours.

ANOVA tests indicate that the difference in resistance to abrasion between PA; PE; PES, PP and Dyneema were highly significant (F = 86.4, F crit = 2.63) as was the difference between PA, PE. PES and PP (F=98.4, F crit = 2.88). The loss of breaking strength of PA was not significantly greater than in Dyneema (F=8.7, F crit =3.3) (Appendix 6).

4.6 Length changes in water

Netting yarn made of PES, PE, PP and Dyneema fibres remained practically unaffected by water and it had no significant influence on length. PA netting yarns react differently in water. Some shrink, some lengthen and others remain unchanged. The changes in length of netting yarn 1, 1.5, 2.0, 2.5, 3.0, 3.5, 4, 4.5 mm in diameter whilst in water are shown in table 5.

Table 5: Changes in length for netting yarn in water. Pre-tension 0,25 gf/tex

Changes in length (W)										
Materials										
Mm	PA		PE		PES		PP		Dyneema	
	Rtex	W (%)	Rtex	W (%)	Rtex	W (%)	Rtex	W (%)	Rtex	W (%)
0.5	241	-2								
1	764	-2	694	0	980	0				
1.5	1677	+2	1099	0	2116	0	1163	0.5	535	0
2	2931	0	2105	0	3734	0	2046	0		
2.5	4519	+3	3210	0			3232	0	2046	0
3	6437	+4	4717	0			4953	0	3232	0
3.5	8680	+3	6579	0						
4										

5 DISCUSSION

In the present study only 14 mm rope was tested, and caution should be taken in extrapolating the results to ropes of different diameters.
Ultimately the best indicator of the quality of a rope is the breaking strength. The tests of breaking strength were done with two eye splices, one at each end. Eye splices at the end of the rope will cause approximately 5% loss in breaking strength (Prado 1990). In the research this loss was not taken in consideration so, the results underestimate the true breaking strength for ropes of 14 mm. According with the international standard 1805, all tensile testing machines shall include a pair of suitable devises for to hold the specimen (ISO 1973).
Due to some problems with the equipment only 3 tests were done on Dyneema. For other materials, tests were repeated 10 times.
It is doubtful that the abrasion test adequately reflects the real situation. In spite of the shortcomings of the study listed above, there is enough information to allow a realistic comparison of the materials tested. Their main properties are summarised in table 6.

Table 6: Properties of ropes with 14 mm made of synthetic fibres

Properties	PA	PE	PES	PP	Dyneema
Breaking strength (kN)	31 (V. good)	23 (Good)	31 (V. good)	32 (V. good)	212 (Exc.)
Strength (g/den)	3.41 (Good)	2.72 (Not good)	2.36 (Poor)	4.49 (V. good)	17.4 (Exc.)
Elongation (%)	25	16	19	10	4

	(Exc.)	Good	(V. good)	(Not good)	(Poor)
Elasticity (%)	19 (Good)	31 (Not good)	24 (Not good)	63 (Poor)	12 (V. good)
Res. to abrasion (% loss in breaking strength)	19 Good	31 Not good	24 Not good	63 Poor	12 V. good
Length changes in water	Yes	No	No	No	No
Density	Sinks	Floats	Sinks	Float	Neutral

V.Good = Very good; Exc.= excellent

The following observations can be made about the results of this study and constitute the main points of the results:

- Synthetic materials are generally strong. The breaking strength of Dyneema is greater than that of other material. This aspect is the most important quality of this synthetic fiber.
- According to the Dyneema manufacturer, the material has much higher abrasion resistance compared with other synthetic fibres (Hampidjan 1999). This statement should be taken with some reservation. In this study Dyneema lost 12% of the initial breaking strength in an abrasion test, which was less than found for other materials. But this loss represented 92 kN which in absolute terms is a greater loss than was observed in any of the others materials. During the abrasion tests we observed that Dyneema rope in contact with unpolished or corroded steel showed more visible signs of damage than the other materials. Flexing and bending however was no problem and the twines remained flexible.
- PA netting yarns react differently in water. Some shrink, some lengthen and some remain unchanged. Unfortunately this study does not provide enough data to discuss the significance of these changes with regard to mesh size, but according to Klust (1982) the influence of water on the mesh size is in principle the same as on length of netting yarns.

Table 6 shows that the synthetic materials are all very good, although no ideal material exists. The problem therefore is to select the best available material for a specific purpose. The selection will depend on the quality of the material, the type of gear to be constructed, how and where it will be used and not least it will depend on price and availability.

Bottom trawl nets require materials, which do not float, has high breaking strength, high elongation and elasticity, and high abrasion resistance. PA, PES and PE are at present the most commonly used materials in bottom trawls. Although not perfect, PA and PES meet most of criteria. PE however, is less expensive.

Most of the properties required for bottom trawls are also required for mid-water trawls. PA is at present the most commonly used material for mid-water trawls but Dyneema is a good substitute for PA. The use of Dyneema twines in nets or parts of nets will substantially reduce the weight of the net. This will of course reduce the resistance in the water and the drag. The lower drag can also be exploited by towing a larger net with the same engine capacity and so raising fishing efficiency. In general, fish have a greater chance of escaping a mid-water trawl than a bottom trawl. By making the mid-water trawls larger this disadvantage can be reduced to some extent. Hampidjan has recently constructed the world's largest mid-water trawl (Hampidjan 1998). This trawl, called Gloria, is made of Dyneema. The main drawback of Dyneema is the high price.

For purse seines the requirements are determined by the operational characteristics of the gear. The most important features are fast sinking rates, high breaking strength, low resistance to water and a good price. At present no materials have all these properties. On the whole the most suitable material is PA. Due to the low elongation, the capacity to float and the excellent elasticity Dyneema is maybe suitable for use in the float rope.
Gillnets are set on the bottom, anchored floating, drifting or encircling. Material for gillnets should have the lowest possible visibility in water, enough strength to withstand the forces of the entangled fish, appropriate elongation and elasticity. No materials combine all these properties, but due to their transparency PA monofilament are the most common. In gillnets, Dyneema is not a good choice. Apart from the prohibitive price, it has a low elongation, reducing the catcability of the gillnet.
For a long-line all of synthetic fibres can be used.

Cape Verde fisheries are small-scale, the fishing gear is fairly basic, but even so, material represent the major part of the total fishing investment. Cape Verde Islands are of volcanic origin and the bottom is rough, causing a great deal of wear and tear of gear. The current on the bottom is strong and consequently the risk of gear loss is high. Fishermen have financial limitation and little knowledge of the properties of materials. For these reasons the material actually used in fishing gear will not depend so much on technical suitability as on local availability and price. It is important for Cape Verde fisheries that private companies compete with INDP. To make this possible the government needs to accord the same facilities and support to all entrepreneurs.
PA and PE are the most commonly used materials in Cape Verde fisheries (Table 1). PA netting is used in purse seines, beach seines and gillnets (mono-filament) and PE in the work ropes (float ropes, footrope). PA is used correctly but the use of PE is not appropriate. The results of this study show that the physical properties of PE (lower breaking strength, less elasticity, poor abrasion resistance) compare unfavourably with those of PA, PES and PP. The popularity of PE is partly due to the low price. In Cape Verde PE is the cheapest of all synthetic fibre products.
Fish aggregating devices (FAD) are used in Cape Verde for concentrating fish in sufficient numbers for purse seining and to localise the fishing ground. FAD is a non-rigid structure which is secured to the bottom by an anchor, rises vertically through the water column and is suspend by means of a surface buoy. Devices designed to attract and temporarily retain desired fish species are attached to the vertical mooring line. FADs are moored both in shallow and deep water (between 150 - 2000 meters depth). The must common materials used in the anchor line are braided PP and PA. The diameter and the length depend on the depth of the water. Due the to the high wear and tear in Cape Verde and the strong currents the lifetime of FADs in deep waters is approximately 3 months (Ramos 1998). Due to the importance of FADs and the cost (approx. USD 1000) (Ramos 1998) it is recommended that INDP make some experiments using Dyneema Sk7 in the anchor line. Saga Petroleum has tested a Dyneema rope in the mooring of an oil rig in 280 m deep water at the Norwegian coast (DSM 97). According to this study Dyneema is much lighter and about the same strength as a wire rope of same diameter. Compared to a polyester rope it is much lighter as well as much thinner. These are great advantages, but most important in handling is the fact that a Dyneema rope has neutral buoyancy. This means that the pressure on the rope is practically independent of its length. This results in a relatively

simple installation procedure for the anchors. The use of Dyneema will increase the cost of the FADs but this might be offset by a longer lifetime of the FADs.

6 RECOMMENDATIONS

When new materials are put on the market, manufactures usually claim that these fibres are well suited for fishing gear. The arguments of manufactures are not always based on exact testing and controlled experiments, but are sometimes speculative. Manufacturers advertising should be considered with caution.
Commercialisation of fishing materials in Cape Verde, should be a private activity. INDP should put an emphasis on investigations of fishing techniques. The work of the research department for fishing gear and methods should be concerned with the following main aspects:

- Textile materials for the production of fishing gear
- Treatment and maintenance of fishing gear
- Location and detection of fish
- Design and constructions of fishing gear
- Application of fishing gear and methods.

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APPENDIX 1: SYNTHETIC FIBRES AND COMMERCIAL NAMES.

Polyamide (PA)
Amilan (Jap)
Anid (Rus)
Anzalon (Neth)
Caprolan (USA)
Denderon (E.Ger)
Enkalon (Neth, UK)
Forlion (Ital)
Kapron (Rus)
Kenlon (UK)
Knoxloc (UK)
Lilion (Ital)
Nailon (Ital)
Nailonsix (Braz)
Nylon (many coun.)
Platil (Ger)
Relon (Roum)
Roblon (Den)
Silon (Czec)
Perlon (Ger)

Polyethylene (PE)
Akvaflex (Nor)
Cerfil (Port)
Corfiplaste (Port)
Courlene (UK)
Drylene 3 (UK)
Etylon (Jap)
Flotten (Fran)
Hiralon (Jap)
Hi-Zen (Jap)
Hostalen G (Ger)
Lavaten (Swed)
Levilene (Ital)
Marlin PE (Ice)
Norfil (UK)
Northylen (Ger)
Nymplex (Neth)
Rigidex (UK)
Sainthene (Fr)
Trofil (Ger)
Velon PS (USA)
Vestolen A (Ger)

Polypropylene (PP)
Akvaflex PP (Nor)
Courlene PY (UK)
Danaflex (Den)
Drylene 6 (UK)
Hostalen PP (ger)
Meraklon (Ital)
Multiflex (Den)
Nufil (UK)
Prolene (Arg)
Ribofil (Ger)
Trofil P (ger)
Ulstron (UK)
Velon P (USA)
Vestolen P (Ger)

Copolymers (PVD)
Clorene (Fran)
Dynel (USA)
Kurehalon (Jap)
Saran (Jap, USA)
Tiviron (Jap)
Velon (USA)
Wynene (Can)

Polyester (PES)
Dacron (USA)
Diolen (Ger)
Grisuten (Ger)
Tergal (Fran)
Terital (Ital)
Terlenka (Neth,UK)
Tetoron (Jap)
Terylene (UK)
Tevira (Ger)

Polyvinyl alcohol (PVA)
Cremona (Jap)
Kanebian (Jap)
Kuralon (Jap)
Kuremona (Jap)
Manryo (Jap)
Mewlon (Jap)
Trawlon (Jap)
Vinylon (Jap)

Commercial names of combined twines for netting	
Kyokurin	Cont. fil PA + Saran
Livlon	Cont. fil PA + Saran
Marlon A	Cont. fil PA + St. PVA
Marlon B	Cont. fil PA + Saran
Marlon C	Cont. fil PA + Cont. fil PVC
Marlon D	Cont. fil PA + Saran
Marlon E	Cont. fil PA + St. PVA (or PVC)
Marumoron	Cont. fil PA + St. PVA
Polex	PE + Saran
Polysara	PE + Saran
Polytex	PE + Cont. fil. PVC
Ryolon	Cont. fil. PES + Cont. fil.PVC
Saran-N	Cont. fil PA + Saran
Tailon	Cont. fil PA + St. PA
Temimex	St. PVA + St. PVC
	Cont. fil = Continuous fibres
	St = Staple fibres

Source: Fisherman's workbook (FAO 1990)

APPENDIX 2: IDENTIFICATION OF SYNTHETIC FIBRES.

Properties	PA	PES	PE	PP	Dyneema[3]
Floats	No	No	Yes	Yes	Yes
-Continuos fibres -Short fibres -Mono-filaments -Sheets	A B B C	A B B C	C C A B	A B B A	C C A A
Combustion	Melts following short duration of heating-forms molten droplets	Melts and burns slowly with bright yellow flame	Melts and burns slowly with pale blue flame	Melts and burns slowly with pale blue flame	Melts and burns slowly with pale blue flame
Smoke	White	Black with soot	White	White	White
Smell	Celery - like fish odour	Hot oil faintly sweet	Snuffed out candle	Hot wax/burning asphalt	Snuffed out candle
Residue	Solid Yellowish rounds droplets	Solid blackish droplets	Solid droplets	Solid brown droplets	Solid droplets

A = Commonly available
B = Material exists but is less common
C = Not available
Source: Fisherman's workbook

APPENDIX 3: VALUES OF BREAKING STRENGTH OF ROPES 14 MM IN DIAMETER.

Sample	PA kN	PE kN	PES kN	PP kN	Dyneema kN
1	30.2	24	34	31.9	218
2	32.2	23.6	31.2	33.2	195
3	32.2	23.4	32.5	31.6	224
4	32.7	23.6	33.1	31.7	
5	32.8	23.3	30.7	31.6	
6	31.7	23.6	29.3	31.3	
7	29.5	23.1	31.3	33.8	
8	32.9	23.7	32.6	33.2	
9	27.9	23.1	29.7	31.9	
10	30.6	23.3	32.3	31.8	
Sum	312.7	234.7	316.7	322.0	637
Average	31.27	23.47	31.67	32.20	212.33
Variance	2.782	0.080	2.247	0.742	234.33
St.dev.	1.67	0.28	1.50	0.86	15.31

[3] The information about Dyneema is given by the promoter of this project. The sense of the smell is subjective so information it is given here with reservation.

ANOVA SINGLE FACTOR

PA, PE, PES, PP, Dyneema
ANOVA

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	93645.96	4	23411.49	1706.48	2.6289E-42	2.619
Within Groups	521.33	38	13.72			
Total	94167.29	42				

PA, PE, PES, PP
ANOVA

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	513.99	3	171.33	117.12	1.2481E-18	2.86
Within Groups	52.66	36	1.46			
Total	566.65	39				

PA, PES, PP
ANOVA

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	4.35	2	2.17	1.13	0.33	3.35
Within Groups	51.94	27	1.92			
Total	56.29	29				

APPENDIX 4: VALUES OF ELONGATION OF ROPES WITH 14 MM OF DIAMETER.

N	PA			PE			PES			PP			Dyneema		
	L_1 Cm	L_2 Cm	E %	L_1 Cm	L_2 Cm	E %	L_1 Cm	L_2 cm	E %	L_1 cm	L_2 cm	E %	L_1 Cm	L_2 cm	E %
1	130	160	23.0	127	146	14.9	123	144	17.1	110	120	9.1	102	107	4.6
2	126	157	25.6	121	141	17.3	101	119	17.8	117	130	11.1	100	103	2.9
3	131	164	29.0	122	132	16.5	117	138	17.9	117	128	9.4	110	114	3.5
4	141	176	24.8	120	140	16.6	126	149	18.3	110	121	10.0	120	126	4.7
5	140	174	27.8	106	122	15.0	110	129	17.3	124	127	9.0	112	117	4.2
6	137	170	24.0	109	127	16.5	117	137	17.1	114	122	7.0	116	119	2.5
7	147	180	22.4	113	130	15.0	118	139	18.0	125	138	10.4	114	119	4.2
8	136	168	23.5	122	141	15.5	132	155	17.4	111	123	10.8	104	108	3.7
9	136	169	24.2	122	142	16.3	120	142	18.3	120	133	10.8	107	109	1.8
10	131	164	29.0	116	135	16.3	102	130	27.5	123	135	9.8	110	116	5.1

L_1 = Length of sample in the first pre-tension
L_2 = Length of sample stressed at 75% of breaking strength
E % = Difference between L_1 and L_2

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance	St. deviation
PA	10	253.3	25.33	5.97	2.44
PE	10	159.9	15.99	0.68	0.82
PES	10	186.7	18.67	9.82	3.14
PP	10	97.4	9.74	1.46	1.21
Dyneema	10	37.2	3.72	1.11	1.05

Between PA, PE, PES, PP and Dyneema
ANOVA

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	2755.834	4	688.9585	180.6383	4.25E-27	2.578737
Within Groups	171.631	45	3.814022			
Total	2927.465	49				

APPENDIX 5: VALUES OF ELASTICITY FOR ROPES, 14 MM IN DIAMETER.

N	PA			PE			PES			PP			Dyneema		
	L_1 Cm	L_2 Cm	E_1 cm	L_1 Cm	L_2 Cm	E_1 cm	L_1 Cm	L_2 cm	E_1 cm	L_1 cm	L_2 cm	E_1 cm	L_1 cm	L_2 cm	E_1 cm
1	130	144	14	127	137	10	123	134	11	110	114	4	102	105	3
2	126	138	12	121	131	10	101	112	11	117	124	7	100	102	2
3	131	145	14	122	126	4	117	125	8	117	122	5	110	111	1
4	141	154	13	120	130	10	126	137	11	110	113	3	120	123	3
5	140	153	13	106	113	7	110	121	11	124	130	6	112	116	4
6	137	152	15	109	120	11	117	125	8	114	119	5	116	117	1
7	147	155	8	113	122	9	118	130	12	125	131	6	114	117	3
8	136	152	16	122	130	8	132	142	10	111	113	2	104	106	2
9	136	153	17	122	133	11	120	132	12	120	125	5	107	109	2
10	131	145	14	116	126	10	102	109	7	123	126	3	110	114	4

L_1 = Length of sample in the first pre-tension ,
L_2 = Length of sample in second pre-tension E = Elastic elongation

N	PA			PE			PES			PP			Dyneema		
	E cm	E_1 cm	L %	E cm	E_1 cm	L %	E cm	E_1 cm	L %	E cm	E_1 cm	L %	E cm	E_1 cm	L %
1	30	14	46.7	19	10	52.6	21	11	52.4	10	4	40.0	5	3	60.0
2	31	12	38.7	20	10	50.0	18	11	61.1	13	7	53.8	3	2	66.7
3	33	14	42.4	10	4	40.0	21	8	38.1	11	5	45.5	4	1	25.0
4	35	13	37.1	20	10	50.0	23	11	47.8	11	3	27.3	6	3	50.0
5	34	13	38.2	16	7	43.8	19	11	57.9	13	6	46.2	5	4	80.0
6	37	15	40.5	18	11	61.1	20	8	40.0	8	5	62.5	3	1	33.3
7	33	8	24.2	17	9	52.9	21	12	57.1	13	6	46.2	5	3	60.0
8	27	16	59.3	19	8	42.1	23	10	43.5	22	2	9.1	4	2	50.0
9	33	17	51.5	20	11	55.0	22	12	54.5	13	5	38.5	2	2	100
10	33	14	42.4	19	10	52.6	28	7	25.0	32	3	9.4	6	4	66.7

E= Total elongation E_1=Elastic elongation L= Elasticity in %⇒ L(%) = E1/E*100

Anova: Single Factor
SUMMARY

Groups	Count	Sum	Average	Variance	St. dev.
PA	10	421	42.1	86.70	9.31
PE	10	500.1	50.01	41.22	6.42
PES	10	477.4	47.74	124.96	11.18
PP	10	378.5	37.85	312.48	17.68
Dyneema	10	591.7	59.17	468.98	21.66

Between PA, PE, PES, PP and Dyneema
ANOVA

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	2647	4	661.87	3.20	0.02	2.58
Within Groups	9309	45	206.87			
Total	11957	49				

APPENDIX 6: VALUES OF RESISTANCE OF ABRASION OF ROPES WITH 14 MM OF DIAMETER.

N	PA			PE			PES			PP			Dyneema		
N	Bs_1 kN	Bs_2 kN	L %	Bs_1 kN	Bs_2 kN	L %	Bs_1 kN	Bs_2 kN	L %	Bs_1 kN	Bs_2 kN	L %	Bs_1 cm	Bs_2 cm	L %
1	30.2	23	23.8	24	14.9	37.9	34	20.8	38.8	31.9	12.9	59.6	218	189	13.3
2	32.2	25.6	20.5	23.6	17.3	26.7	31.2	24.8	20.5	33.2	11.2	66.3	195	176	9.7
3	32.2	29	9.9	23.4	16.5	29.5	32.5	27.4	15.7	31.6	12.9	59.2	224	192	14.3
4	32.7	24.8	24.2	23.6	16.6	29.7	33.1	23.1	30.2	31.7	11	65.3			
5	32.8	27.8	15.2	23.3	15.6	33.0	30.7	23.8	22.5	31.6	11.3	64.2			
6	31.7	24	24.3	23.6	16.5	30.1	29.3	23.1	21.2	33.8	9.7	71.3			
7	29.5	22.4	24.1	23.1	15	35.1	31.3	27.5	12.1	33.2	12.8	61.4			
8	32.9	23.5	28.6	23.7	15.5	34.6	32.6	23.9	26.7	31.9	11.2	64.9			
9	27.9	24.2	13.3	23.1	16.3	29.4	29.7	24.2	18.5	31.8	12.6	60.4			
10	30.6	29	5.2	23.3	16.3	30.0	32.3	20.9	35.3	31.3	11.6	62.9			

Bs_1 = Initial breaking strength
Bs_2 = Breaking strength after submitting sample to 8 hours in a machine for abrasion
L % =Loss of breaking strength in %

Anova: Single Factor

Groups	Count	Sum	Average	Variance	St. dev.
PA	10	188.5	18.85	57.16	7.56
PE	8	251.84	31.48	12.75	3.57
PES	10	241	24.1	72.80	8.53
PP	10	634.9	63.49	13.73	3.71
Dyneema	3	37.2	12.4	5.67	2.38

Between PA, PE, PES, PP and Dyneema

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	13382.28	4	3345.57	86.41	6.05E-18	2.63
Within Groups	1393.79	36	38.72			
Total	14776.08	40				

Between PA, PE, PES and PP

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	12007.27	3	4002.42	98.43547	7.78E-17	2.88
Within Groups	1382.45	34	40.66			
Total	13389.72	37				

Between PA, PE, PES

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	821.7901	2	410.8951	8.713482	0.001203	3.354131
Within Groups	1273.218	27	47.15624			
Total	2095.009	29				

Between PA, Dyneema

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	96.00577	1	96.00577	2.008699	0.184096	4.844338
Within Groups	525.745	11	47.795			
Total	621.7508	12				