CHAPTER 3

HIGH STRENGTH SYNTHETIC FIBER ROPES

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1.0 INTRODUCTION

Chapter 3 describes ropes made from high strength synthetic materials for oceanographic towing, mooring and lifting. The chapter is broken in four main sections.

High strength synthetic rope compared to wire

Materials available for rope construction

Constructional changes that alter rope performance

Summary and Reference Material

2.0 HIGH STRENGTH SYNTHETIC FIBER ROPES VS STEEL

A primary advantage of Synthetic Fiber Rope is their lightweight. Lightweight lines are easier to handle and reduce topside weight. High Strength Synthetic Fiber Rope also can be used in greater depths than wire.

2.A Weight Comparison

Kevlar density is less than 1/5 that of steel and Spectra's density is less than 1/8 that of steel. A 1" Kevlar, Spectra, and wire each have approximately 125,000 pound break strength. However, the weight per 100/ft is very different:

	Approximate Weight/100'	
	in air	in water
Steel	185 Lbs.	161 Lbs.
Kevlar	36 Lbs.	10 Lbs.
Spectra	26 Lbs.	0 Lbs.

2.B Payload Comparison in Water

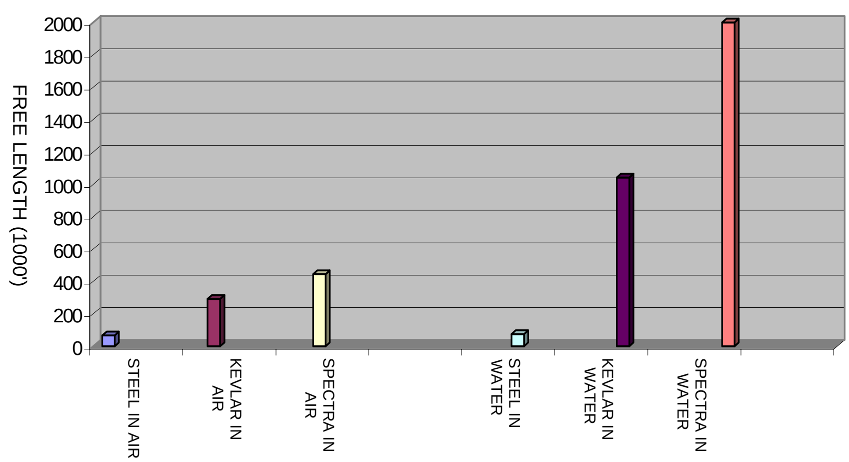
There are significant weight savings when synthetic rope is used in water. As stated above, Kevlar rope is 1/5 the weight of steel in air. In water, Kevlar weighs 28% of its weight in air. This means significantly higher payloads in oceanographic lifting. An extreme example is a 20,000 foot long, 1/2" wire rope (8,570 pound working load - 25,700 pound break strength). The rope itself weighs 6,820 pounds. With 1,000 pounds needed for over-pull, the payload of this system is 750 pounds.

A 1/2" diameter Kevlar rope could be used in this system, still getting the required 26,000-pound break strength, but 20,000 feet of rope would weigh 500 pounds in water. Assume the same 1,000 pound over-pull, the payload can be increased fivefold to 3,750 pounds. Using Kevlar, the total system would have a factor of safety approximately 5 to 1, not the 3 to 1 of steel.

2.C Free Length

Free length is that length at which a rope breaks under its own weight. It can be found by dividing a rope's break strength by its weight per foot. Taking the same 1/2" diameter rope discussed above, Figure 3-1 shows graphically, the difference between steel, Kevlar, and Spectra ropes in air and sea water.

FIG 3-1



2.1 FATIGUE RESISTANCE

The fatigue properties of synthetic rope are outstanding and the rope's construction can be adjusted to achieve additional cyclic life.

2.1.A Bend Over Sheaves

Kevlar ropes have been demonstrated to withstand 50,000 bending cycles over sheaves forty times the rope's outside diameter at 35% of the rated break strength, without failure. Residual strength is 95% of rope's original rated break strength. Therefore, Kevlar rope's performance, under these conditions, is comparable to 6 strand steel wire rope that is not torque balanced.

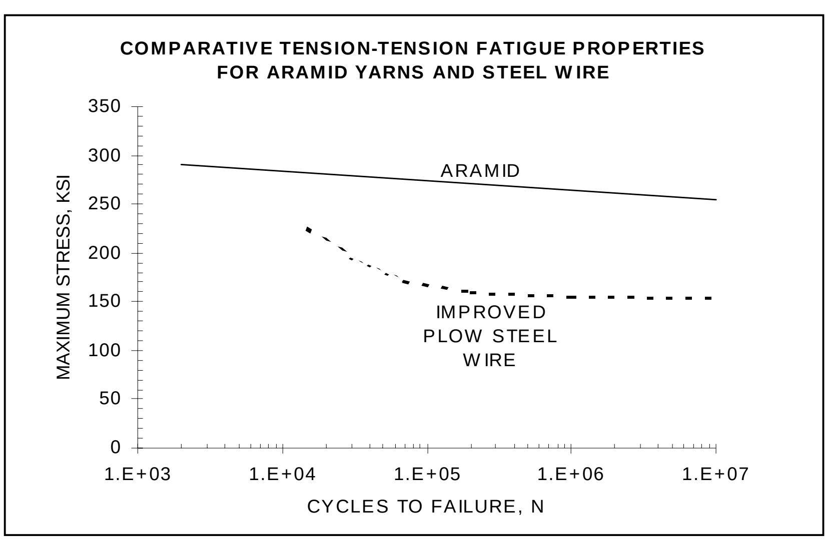
Kevlar has been demonstrated to have outstanding performance at a sheave diameter/rope diameter (D/d) ratio of 40:1 and a relatively high factor of safety. It is more common, however, to use Kevlar ropes at a 25 to 1 or 30 to 1 D/d ratio and a 5 to 1 or 6 to 1 factor of safety.

Space limitations can limit the sheave size. D/d's as small as 20 to 1 have been used but reduced fatigue life. Endless cycling of the same section of a rope, as on a motion compensator, can wear a rope locally, due to the fast accumulation of bending cycles. In either case special rope designs can be produced that will extend fatigue life.

2.1.B Tension-Tension Fatigue

Since all ropes are subject to fluctuating loads, tension-tension fatigue performance is an extremely important characteristic. Figure 3-2 shows the superior fatigue performance of Kevlar 29 yarn to improved plow steel wire. Residual strength of Kevlar 29 and steel wire at 10,000,000 cycles was above 95% for both materials.

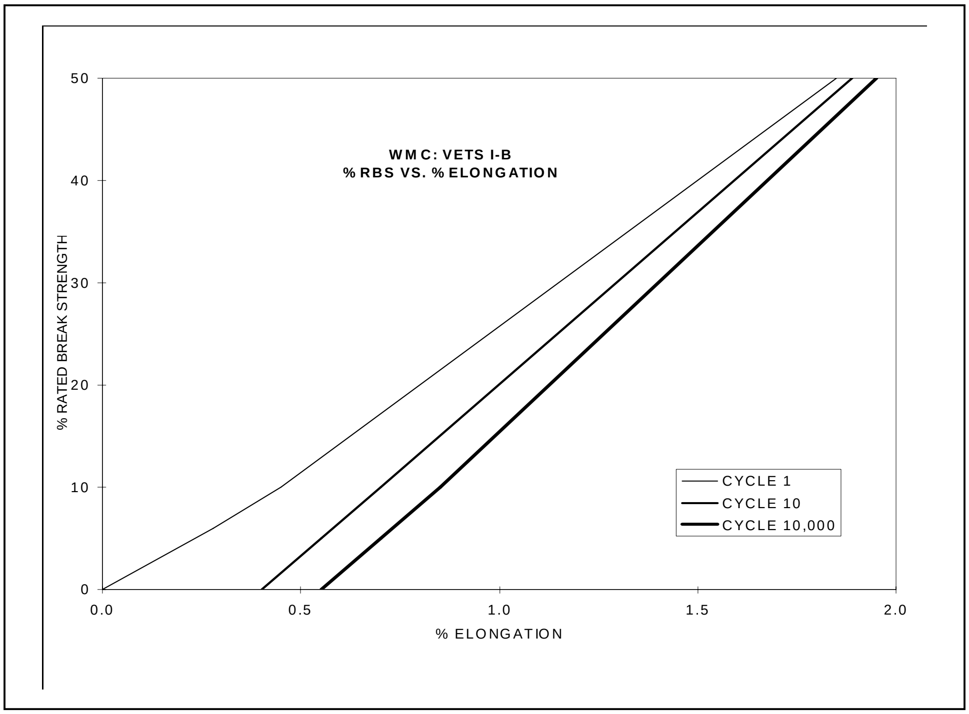
FIG 3-2



2.2 LOW STRETCH

Due to the high modulus of Kevlar there is minimal stretch and stored energy over the working load range. Figure 3-3 is a load-elongation curve for Kevlar. Ropes made from other synthetic fibers like nylon have about 10 times the stretch of Kevlar. Low stretch gives the user better control over the load's position and faster reactions to the load touching the bottom.

FIG 3-3



Less stretch also means less stored energy in Kevlar ropes. That can be invaluable. For example, taking a core sample, there is one tenth the recoil with Kevlar than nylon rope. Less recoil reduces the damage to the core sample.

2.3 DISADVANTAGES

The main disadvantage of these materials is that they are easy to damage. Being less tough than steel wire rope, synthetic rope shows the damage it receives. Wire rope damage often tends to look less severe than it actually is and is frequently used even when it should be retired.

3.0 MATERIALS

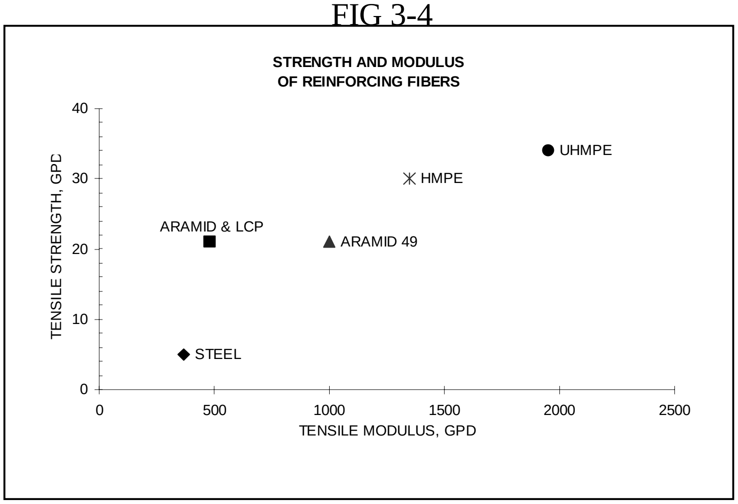
Several fibers are currently available for rope in oceanographic applications. Several of the material's physical properties are compared numerically in the following table. Figure 3-4 graphs the materials specific strength vs specific tensile modulus.

Physical Property Comparison of
Kevlar, Sepectra, and Steel

	Kevlar 29	Kevlar 49	Spectra 900	Spectra 1000	Steel
Tenacity (gpd)	23	23	30	35	2.9
(psi)	400,000	400,000	375,000	435,000	285,000
Modulus (gpd)	525	850	1400	2000	200
(1,000,000 psi)	10	18	17	25	30
Elongation (%)	3.7	2.5	3.5	2.7	2.0
Density (g/cc)	1.44	1.44	.97	.97	7.86
Meltig Point (°C)	500°**	500°**	147°	147°	>1199°
Denier	1500	1500	1200	650	
No. of Filaments	1000	1000	118	120	

*Galvanized Improved Plow Steel
**Does not melt - It chars

FIG 3-4



3.A Kevlar

DuPont introduced two para-bonded aromatic polyamide fibers, Kevlar 29 and Kevlar 49, in 1971. Kevlar exhibits high strength, high flexibility, high modulus, low elongation, low density, non-conductivity, and corrosion resistance. Kevlar also has exceptional thermal stability over a wide range of temperatures, from -46°C to 160°C with minimal change in tensile strength. Kevlar 29 and 49 have similar tensile and thermal properties but Kevlar 49 has higher modulus, lower elongation, and a higher price. Most of the information contained herein applies to Kevlar 29 because of the experience with Kevlar 29 over the years.

3.B Other Aramid Fiber

Two types of Aramid are manufactured outside of the United States. Teijin Limted produces Twaron in Holland and Technora in Japan. These fibers demonstrated properties similar to Kevlar except Technora, which shows slightly better chemical resistance to high concentrations of acids and bases. These fibers are available in the United States on a limited basis.

3.C Spectra

Spectra 900 and Spectra 1000 are ultra high modulus polyethylene fibers developed by Honeywell/GE. Spectra fibers combine a high degree of molecular orientation with a density lower than water. Therefore, Spectra can be made into buoyant ropes. Spectra demonstrates high specific modulus, high specific strength, excellent chemical resistance, and high abrasion resistance. The disadvantages of Spectra are its high price, tendency to creep, and limited temperature range. Principal advantages are lighter weight (buoyant) and longer cyclic bend over sheave flex life.

4.0 JACKETS

For use on oceanographic winch applications Kevlar ropes generally require protective jackets. Such jackets are intended to provide protection from ultraviolet light and external abrasion.

4.A Braided Jackets

Several fiber materials have been evaluated for braided jackets and polyester has proven best for general purpose use. Polyester stays tight on the rope and facilities load transfer from the force of a traction winch to the rope.

Braided polyester is relatively soft and conforms to the outside surface of the Kevlar assuring direct load transfer while cushioning and protecting the load bearing fiber.

4.B Extruded Plastic Jackets

Polyurethane, Polyethelene, Zytel, Hytrel and other materials have been used for protective jackets. Such materials provide somewhat better protection from ultraviolet light and other environmental considerations but generally lack the toughness to protect the rope from abrasion. For long term standing rigging, such as tower guy, extruded jackets perform well but they are not recommended for working ropes.

When a rope is in tension the diameter may be reduced, thus causing the jacket to become a loose sleeve. When pulled around a traction the jacket will bunch up and tear.

4.C Combination Jackets

For extreme cases, combination jackets have been successful. For combination jackets the rope first has an open braid with about 50% coverage applied to the Kevlar rope. The desired plastic is then pressure extruded into the rope. The braid provides a form of fiber reinforcement to the plastic as they become interlocked.

Such jackets provide a degree of better protection but increase diameter (more drag), bending stiffness, weight, and cost.

5.0 TERMINATIONS

The final break strength of a rope is often determined by the efficiency of the rope's termination. Some terminating techniques can develop a rope's full break strength, while others severely limit the break strength. Ropes can be supplied already terminated or the user can terminate them himself as needed.

5.A Improved "Hood" Splice

The best terminations of the multi-strand ropes with a single jacket is the Improved "Hood" Splice. It is a modification of the Braidback Splice and develops 100% of the break strength of a rope. Directions for this splice are beyond the scope of this paper but may be obtained from the writer.

5.B Eye Splice

An efficient method to terminate jacketed ropes is the eye splice, similar to the splices used for wire and natural fiber ropes. These splices are constructed by forming an eye near the end of the rope, then tucking the tails of the rope back into the rope's body. The point where the last tuck enters the rope is where it usually fails. The actual type of splice required depends on the rope's construction. Detailed splicing directions for many types of ropes are available from the manufacturer.

5.C Mechanical Terminations

Several forms of mechanical terminations have been tested with Kevlar ropes including: potted epoxy plugs, swage fitting, nicopress sleaves, and wire rope clips. These terminations develop 50% - 75% of the rated break strength of a rope due to problems with load concentration at the end of termination. These terminations may be useful in applications where rope has excess strength and quick easy terminations are important.

Testing to-date, of mechanical terminations, are basically break strength. Cyclic tension-tension fatigue tests, at reasonable working levels, should be conducted before selecting a mechanical termination for a dynamic application.

6.0 OTHER CONSTRUCTIONS AND APPLICATIONS

This chapter discusses only two constructions of synthetic rope that perform well with oceanographic winch systems. Kevlar ropes are made in most wire rope constructions for wide variety of applications. Some additional uses of Kevlar and Spectra ropes include:

Oceanographic Mooring
Balloon Tethers
Mine Sweep Cables
Riser Tensioners
Moorings on Oil Rigs
Winch Lines for Utility Trucks
Helicopter Slings
Oil Containment Booms
Lift Lines of Cranes

7.0 SUMMARY

Since there are so many uses for synthetic rope, it is impossible to have one material or construction to suit each application, making a variety of ropes necessary. However, for most oceanographic lifting applications the WMC:VETS 1-B type, stranded Kevlar ropes, listed in the "User Information" section, provide a good combination of characteristics. These characteristics include: small diameter, light weight, low stretch, torque balance with good bend over sheave, and outstanding tension-tension fatigue life. Combining these types of rope with a reliable termination provided 100% strength translation.

7.A Reference Tables

KEVLAR

Outside Diameter (inches)	**Break Strength (pounds)**	**Weight In Air (lb./1000')**
3/16	3,500	16
1/4	7,500	28
5/16	12,000	40
3/8	17,800	62
7/16	23,500	74
1/2	28,750	89
9/16	37,500	102
5/8	46,000	128
3/4	63,000	180
7/8	89,000	255
1	125,000	360
1-1/4	160,000	520
1-1/2	200,000	600

SPECTRA

Outside Diameter (inches)	Break Strength (pounds)	Weight In Air (lb./1000')
3/16	3,200	12
1/4	6,800	21
5/16	11,000	29
3/8	16,500	45
7/16	22,500	54
1/2	28,500	64
9/16	35,000	78
5/8	43,500	100
3/4	59,500	137
7/8	85,000	195
1	120,000	274
1-1/4	165,000	368
1-1/2	200,000	460

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