Chapter 2

Rope Properties

2.1 General Characteristics

Samson Rope Technologies in Ferndale, Washington manufactured all of the ropes tested during the project. Many different rope manufacturers were considered prior to making the final decision. Some of these rope manufacturers were Yale Cordage, Neocorp, Pigeon Mountain Industries (PMI), Rocky Mount Cord Company, Frank W. Winne and Son, Incorporated, Cortland Pudget Sound Cordage, and Phillystrand. Samson Rope Technologies was an attractive choice because of their ability to manufacture ropes as well as terminate the ends with eye splices. Also, they had a wide range of synthetic fiber ropes to choose from. Many of the aforementioned rope manufacturers could provide the ropes but did not have the splicing capabilities. Valuable information on synthetic fiber ropes was given by Dr. Forrest Sloan (Cortland Cable Company), Tom Yale (Yale Cordage), Dr. C.M. Leech (University of Manchester Institute of Science and Technology), and Dr. R. Chou (Samson Rope Technologies).

As mentioned earlier, it was not until the 1940's that the first synthetic fiber (nylon) was developed. Nylon fiber spawned a rapid growth event in the synthetic fiber industry, which allowed some fibers to be stronger than steel. The developments in the industry continue to broaden the spectrum in which synthetic fiber ropes can be utilized. Physical characteristics such as strength, weight, firmness, and stretch can be optimized to create all types of ropes. The primary fibers that are utilized by Samson Rope Technologies are cotton, sisal, nylon, polyester, aramid (Kevlar), polypropylene, polyethylene, LCP (Vectran), and HMPE or UHMWPE (ultra-high molecular weight polyethylene). Samson Rope Technologies uses different combinations of these fibers to create a wide range of synthetic fiber ropes.

Nylon fiber is the cornerstone in the development of all synthetic fibers. The fiber is made of nylon filaments, which are naturally pure white and continuous for several hundred feet. These filaments consist of long synthetic molecular chains called polyamides, which are made by rearranging the compound chemicals from coal, petroleum, and agricultural residues. Nylon fiber has a very high ultimate strength and good elasticity. It is extremely flexible and tough while having the advantage of high stretch and recovery. Prolonged exposure to extreme temperatures and sunlight can cause a reduction in strength.

Similar to nylon, polyester is made by rearranging the chemicals of simpler compounds derived from petroleum and coal. The synthetic molecular chains are very long and are combined to make naturally white continuous filaments. While polyester fiber is almost as strong as nylon fiber, the tendency to stretch is much lower, which was a desirable quality. Internal wearing and sunlight do not compromise the integrity of the fibers. Polyester also has excellent repeat loading ability and performs equally under wet or dry conditions. Polyester fibers and almost all nylon fibers are very fine and hair-like.

Polypropylene is an extruded thermoplastic fiber made by rearranging the chemical structure of simpler compounds from petroleum or natural gas. This fiber is extremely susceptible to high temperatures and sunlight (UV rays). It is very versatile and more shock absorbent than polyester, but it is much weaker and does not recover as well as nylon or polyester. Polypropylene is encountered in several different forms in ropes. It is sometimes a thin multifilament fiber, similar to but slightly thicker than polyester and nylon. It can also be a thicker monofilament, resembling straw or bristles. As mentioned earlier, polypropylene is used primarily in marine applications and has a lower modulus of elasticity than most of the other synthetic fibers.

Polyethylene fiber is produced by polymerizing or melt spinning ethylene. The way in which polyethylene is manufactured has a great influence on the outcome of the mechanical properties it possesses. These fibers can be as much as three times as strong as nylon fibers if manufactured correctly. Polyethylene is very flexible and has very low creep tendencies. Polyethylene fibers typically are bristle-like and are thus similar to the monofilament form of polypropylene. This type of fiber is not as common as the other fibers, but is still used in some applications.

LCP or LCAP (Vectran) fibers have a very high modulus and a very high resistance to heat. These fibers are produced by melt spinning from thermotropic liquid crystalline aromatic polyester. As mentioned earlier, the cost of producing this type of fiber is slightly higher than similar fibers, and is not used as often in the synthetic fiber rope industry. LCP is a very fine tan or dirty yellow colored fiber similar to, but not as yellow as, aramid. The most attractive qualities of this fiber are the high strength-to-weight ratio it possesses and its excellent fatigue resistance.

Aramid (Kevlar) fibers have been the subject of intense research and development for many years. Kevlar is used in many applications other than synthetic fiber ropes. Its strength-to-weight ratio is five times that of steel and it has excellent resistance to heat. Kevlar filaments consist of very long synthetic molecular chains formed by rearranging the chemical structure of aromatic polyamides. Aramid is a very fine straw-colored fiber that is twice as strong as nylon and 19% heavier than nylon. These fibers have the tendency to break when repeatedly flexed and are susceptible to axial compression fatigue.

Olefin fibers, which are a combination of polypropylene and polyethylene fibers, are very lightweight and considerably stronger than polypropylene fibers, while the elongation percentages for this fiber are moderate. This fiber is an example of the leading and most recent developments in improved synthetic fiber technology. Excellent abrasion resistance and the lightweight nature of olefin fibers make this material one of the most often used synthetic fibers.

High molecular weight polyethylene (HMPE) fibers are also known as Spectra or Dyneema. Its strength-to-weight ratio is ten times that of steel and it is up to 40% stronger than aramid fibers. HMPE is known as one of the world’s lightest and strongest fibers and has excellent resilience to dynamic loading. HMPE fibers are produced by gel spinning ultra-high molecular weight polyethylene (UHMWPE), and are very fine and slippery fibers.

2.2 End Terminations

The eye splice is the most common form of end termination for braided synthetic fiber ropes. An eye splice is formed by unlaying the end of a rope for a short distance, then turning the end back to form an eye shape, and tucking the separated strands back into the braided rope. Figure 2.1 shows an example of an eye splice with the individual strands exposed.

Figure 2.1 Typical Eye Splice (Library Rope – www.givemeweb.com)

According to most rope manufacturers and splicing guides, the separated strands should be the length of seven times the rope circumference. In a twelve strand braided rope, the twelve strands should be paired together into combinations of a clockwise twisted strand and a counterclockwise twisted strand. Once the desired eye size is determined, the strand pairs should be inserted into the body of the rope and out of the opposite side. After all strand pairs have been passed through the body of the rope, each strand must be tucked into the body of the rope, making sure that all slack has been taken out of each strand. Each tuck consists of passing a strand pair under two individual strands in the braid and over one strand. Three complete tucks should be made for each of the six strand pairs. From this point, one strand out of each pair should be tucked two more times. All excess strand material should be cut off with a slight portion of the strand protruding from the rope. These protrusions can be bound in tape so that each strand does not slip back into the rope upon loading.

According to Dr. R. Chou of Samson Rope Technologies, eye splices can reduce the breaking strength of a rope by 10%. This number greatly increases with other end termination techniques such as tying the rope in a knot (reduction in breaking strength up to 50%). Other end terminations related to wire ropes were also explored for use in these experiments. Bob Lumbardo of Phillystrand suggests that typical end terminations for wire ropes include spelter sockets, spike cones with internal or external plugs, pottings, and compression fittings. These end terminations can be used with parallel strand synthetic fiber ropes and twisted ropes. Sockets and cones are very similar to each other. The ends of the rope are separated into individual strands and drawn out to a certain length. All strands are pulled through a cylindrical fitting and fanned out so that the strands are evenly distributed around the circumference of the fitting. A cone is then inserted between the strands so that it fits tightly into the cylindrical fitting. This terminates the end of a rope or cable and provides a connection at the end. Potting terminations are very similar to the previous termination techniques except the cone is replaced with a potting resin material. Resin is poured into the cylindrical fitting, where it solidifies, thus terminating the end of a rope or cable. Compression fittings essentially compress the end of a rope inside a cylindrical fitting. The fittings usually have sharp studs that "dig" into the rope strands and keep them from sliding. After exploring all of the aforementioned end termination techniques, the eye splice was the only reasonable option. The end terminations associated with the wire ropes are not a plausible option for braided ropes because the form in which the ropes are braided does not allow for all the strands to be connected to the end termination. If all strands are not connected to the end termination, the total load on the rope is not distributed equally to all strands. This can cause premature failure of the rope under any substantial type of tensile load. Eye splicing evenly distributes the total tensile force to all of the strands within a rope.

As mentioned previously, many rope manufacturers do not have splicing capabilities because of the time and effort involved in the process. Eye splices are hand braided and can take many man-hours of braiding if multiple sets of ropes are desired. As found in this research, the eye splice is the most expensive portion of each rope. Ropes are usually sold on a price-per-foot basis. Factors that affect the price of each rope are the fiber type used in the rope, the type of braid, the diameter size, and the length of the rope. The nine-foot ropes used in the snap loading tests had a negligible price-per-foot cost compared to the cost of two eye splices (one splice at each end).

2.3 Tested Ropes

Eleven different types of synthetic fiber ropes were tested under snap loading. The different types are categorized by the fiber content that is present in each rope. Different fibers have different material properties, thus they have different moduli of elasticity, strength, weight, creep characteristics, etc. Table 2.3.1 shows the dimensions for the precycled ropes (ropes subjected to static load tests prior to dynamic snap load tests) as well as the weight of each rope.

Precycled Ropes (9-ft)	Length	Weight	Diameter (mid-span)	Diameter (below splice)
3/8" Amsteel Blue	9' - 2 1/4"	0.38 lb	0.425"	0.621"
1/2" Amsteel Blue	9' - 1"	0.68 lb	0.545"	0.860"
3/8" Amsteel II	9' - 1 1/2"	0.52 lb	0.386"	0.506"
1/2" Amsteel II	9 - 2"	1.08 lb	0.592"	0.677"
3/8" Amsteel SLV	9' - 2 1/4"	0.40 lb	0.422"	0.607"
1/2" Amsteel SLV	9' - 2"	0.70 lb	0.566"	0.865"
3/8" Tech 12	9' - 2 1/2"	0.50 lb	0.419"	0.656"
1/2" Tech 12	9' - 1/4"	1.02 lb	0.550"	0.885"
3/8" QS Polytron	9' - 1 1/4"	0.32 lb	0.476"	0.661"
1/2" QS Polytron	9' - 2 1/2"	0.62 lb	0.546"	0.822"
3/8" Tenex	9' - 1/2"	0.46 lb	0.372"	0.590"
1/2" Tenex	9' - 3/4"	1.06 lb	0.489"	0.891"
3/4" SSR-1200	8' - 11 1/4"	2.12 lb	0.934"	1.389"
3/4" Round Plait Ultra Blue	9'	1.90 lb	0.976"	1.345"
3/4" Round Plait Polyester	8' - 11 1/2"	2.00 lb	0.956"	1.194"

Table 2.3.1 Weights and Dimensions of Precycled Ropes

Rope lengths were measured with each rope being extended close to the taut state. Rope diameters were measured two times with vernier calipers at two different locations on each rope. An average of the two measurements was taken at mid-span and immediately below the splice. The diameter of each rope immediately below the splice is larger than the mid-span diameter because of the excess strands that are woven back into the rope during the splicing process.

Table 2.3.2 shows the dimensions for the new ropes as well as the weight of each rope.

New Ropes (9-ft)	Length	Weight	Diameter (mid-span)	Diameter (below splice)
3/8" Amsteel Blue	9' - 1 1/4"	0.40 lb	0.388"	0.642"
1/2" Amsteel Blue	8' - 11 1/2"	0.68 lb	0.515"	0.882"
3/8" Amsteel II	9' - 1 1/4"	0.50 lb	0.375"	0.496"
1/2" Amsteel II	9 - 2 1/4"	1.08 lb	0.550"	0.702"
3/8" Amsteel SLV	9' - 1/4"	0.40 lb	0.410"	0.678"
1/2" Amsteel SLV	8' - 11 1/2"	0.72 lb	0.569"	0.890"
3/8" Tech 12	9' - 1 3/4"	0.50 lb	0.381"	0.660"
1/2" Tech 12	8' - 11 1/2"	1.02 lb	0.559"	0.940"
3/8" QS Polytron	9' - 1/4"	0.32 lb	0.404"	0.645"
1/2" QS Polytron	9' - 1 3/4"	0.62 lb	0.555"	0.821"
3/8" Tenex	9' - 3/4"	0.48 lb	0.370"	0.598"
1/2" Tenex	9' - 1/2"	1.04 lb	0.518"	0.872"
3/4" SSR-1200	9'	2.10 lb	0.802"	1.287"
3/4" Round Plait Ultra Blue	8' 11 1/2"	1.82 lb	0.884"	1.390"
3/4" Round Plait Polyester	8' - 11"	2.00 lb	0.756"	1.224"

Table 2.3.2 Weights and Dimensions of New Ropes

The tested ropes were chosen based on fiber content and the amount of stretch that each rope possesses. All nine-foot ropes have three-inch soft eye splices on each end, and all seven-foot ropes have two-inch soft eye splices on each end. Soft eye splices do not have a shield or shackle or other type of protective hardware device attached to them. All ropes are either 12-strand braided ropes or double-braided ropes. Each rope has a distinctive Samthane coating that is applied to all Samson ropes once the braiding process is complete. These coatings improve service life, reduce snagging, enhance abrasion resistance, prevent contamination, and reduce cutting of the rope. These coatings add no improvements in strength or other material property. Different coatings are used on each type of synthetic fiber rope. The following paragraphs will describe in detail the various ropes that were tested under snap loading.

2.3.1 Amsteel Blue

Amsteel Blue (formerly known as Spectron 12 Plus) is one of the more popular ropes that Samson Rope Technologies manufactures. The "Blue" portion of the name is indicative of the rope's color. The blue color comes from a Samthane urethane coating that protects the rope against abrasive surfaces. This rope consists of ultra-high molecular weight polyethylene fibers, mainly Dyneema and Spectra, and has the highest strength-to-weight ratio of all Samson ropes. Another characteristic of this type of rope is its excellent flex fatigue resistance (i.e., ability to transfer from a slack to taut state repeatedly without causing substantial fatigue to individual fibers) compared to many other UHMWPE or HMWPE fiber ropes. This rope is also very light in weight (floats on water), very flexible, and relatively easy to splice. Based on elastic elongation figures at 10% of breaking strength given in the Samson Rope Technologies catalog, Amsteel Blue has the lowest elongation under load of all Samson ropes (approximately 0.44%). Amsteel Blue is also 40% to 45% stronger than regular Amsteel fiber ropes. Once the eye splice has been woven back into the rope, pieces of tape are wrapped around the "loose" strands so that they do not recede back into the rope, which could cause the splice to fail. Three-eighths-inch and one-half-inch diameter Amsteel Blue ropes were used in the snap load tests. Figure 2.2 shows the Amsteel Blue rope with a three-inch eye splice and the taped strands.

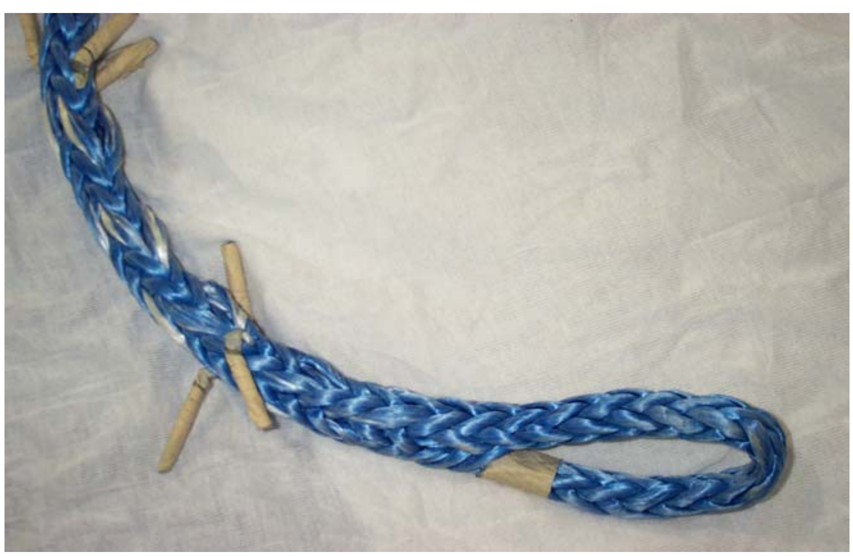

Figure 2.2 Amsteel Blue Synthetic Fiber Rope

2.3.2 Amsteel II

Amsteel II (formerly known as Spectron II) is one of two double-braided ropes that were tested under snap loading. The core of this rope is a braided HMWPE fiber construction, while the outer cover is a braided polyester construction. This combination allows for the high-strength core to carry the majority of the load while the outer cover protects the core from abrasion and wear. The yarn at the base of the eye splice is called whip stitching (lock stitching), which keeps the two braids from separating from each other. According to Dr. R. Chou, whip stitching is used more for aesthetic purposes than performance purposes. With its high strength and low elongation, Amsteel II has superior flex fatigue life. Its elastic elongation is approximately 0.5% at 10% of breaking strength. Three-eighths-inch and one-half-inch diameter ropes were used in the snap load tests. Figure 2.3 shows the Amsteel II synthetic fiber rope.

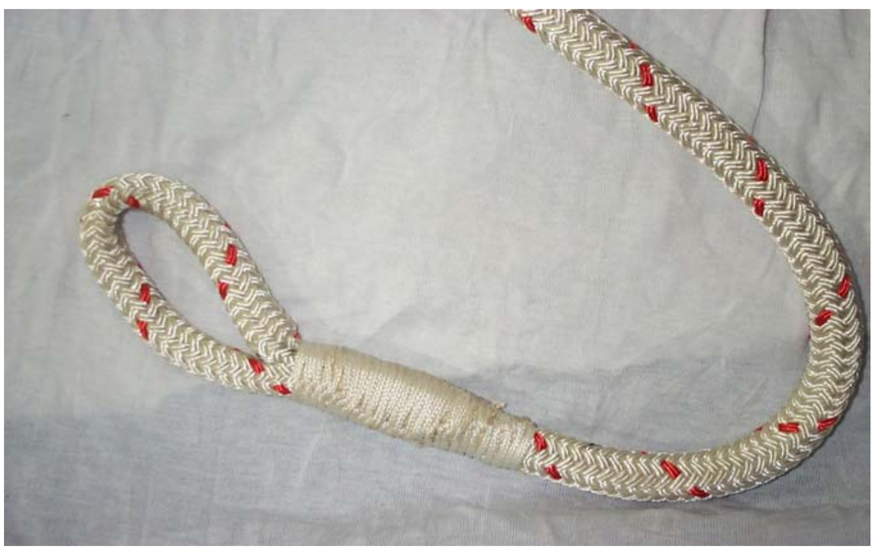

Figure 2.3 Amsteel II Synthetic Fiber Rope

2.3.3 Amsteel

Amsteel or Amsteel SLV is a twelve-strand braided rope of high molecular weight polyethylene (HMWPE) with a grey Samthane urethane coating similar to Amsteel Blue. Along with being one of the more popular ropes in the industry, Amsteel combines high strength with low stretch capabilities. This rope weighs seven times less than a wire rope with the same strength and stretch, and the braided construction allows for no rotation. Amsteel ropes have a specific gravity less than water, thus the ropes will float. These ropes have very good flexural fatigue durability and a long service life. With a comparable strength and elongation to Amsteel Blue, Amsteel ropes are a very attractive alternative to wire ropes. Three-eighths-inch and one-half-inch diameter Amsteel ropes were used in the snap loading tests. Figure 2.4 shows an Amsteel twelve-strand braided rope with a three-inch eye splice and the taped strands at the end of the splice.

Figure 2.4 Amsteel Synthetic Fiber Rope

2.3.4 Tech 12

Tech 12 is a twelve-strand braided rope consisting of Technora (aramid) fibers. This rope has a Samthane urethane UV coating and is easy to splice. Tech 12 has extremely good heat resistance and flex fatigue service life. Its combination of high strength, low stretch, and negligible creep make this rope an attractive source for many different applications. The amount of elastic elongation for Tech 12 is slightly more than that of the Amsteel fiber ropes (approximately 0.63% at 10% of breaking strength). One drawback to Tech 12 is that the aramid fibers are susceptible to axial compression fatigue as was mentioned previously. Three-eighths-inch and one-half-inch diameter Tech 12 ropes were used in the snap loading tests. Figure 2.5 shows a Tech 12 synthetic fiber rope with a three-inch eye splice.

Figure 2.5 Tech 12 Synthetic Fiber Rope

2.3.5 Quick-Splice Polytron

Quick-Splice Polytron or QS Polytron is a twelve-strand or eight-strand single-braided rope consisting of Ultra Blue copolymer olefin fibers. Ultra Blue is a trademark name by Samson Rope Technologies that describes their form of olefin fiber. This rope is easy to splice, floats on water, and has a very high resistance to sunlight degradation. It has very high strength and has an elastic elongation of about 1.1% at 10% of breaking strength. Three-eighths-inch and one-half-inch diameter QS Polytron ropes were used in the snap loading tests. The three-eighths inch QS Polytron rope is an eight-strand single-braided rope. Diameter sizes greater than seven-sixteenths inch are twelve-strand single-braided ropes. Figure 2.6 shows a QS Polytron rope with a three-inch eye splice. Also shown in the figure is the whip stitching for a single braided rope. The whip stitching essentially locks the strands into the rope once the eye splice has been rewoven back into the rope.

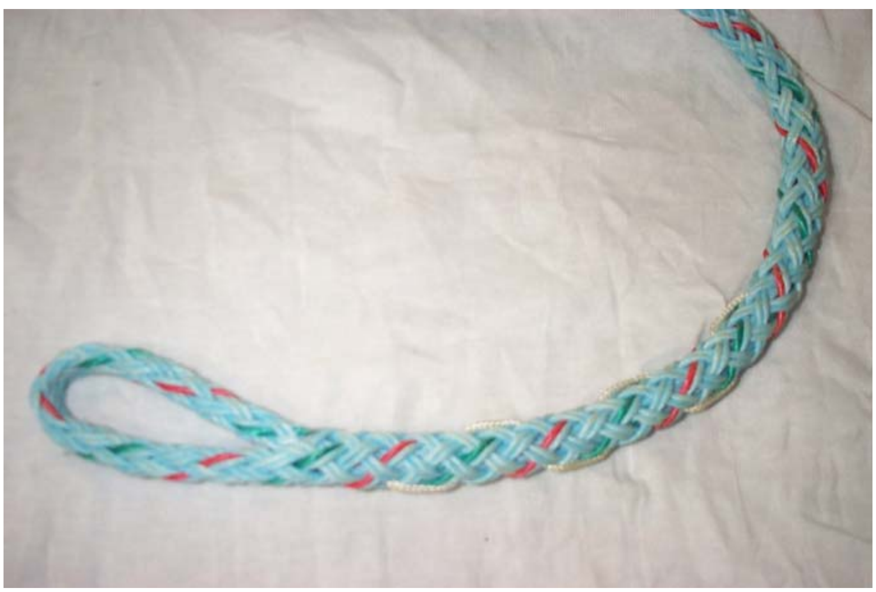

Figure 2.6 Quick-Splice Polytron Synthetic Fiber Rope

2.3.6 Round Plait Ultra Blue

Round Plait Ultra Blue or RP Ultra Blue is very similar to QS Polytron, for it is a twelve-strand single-braided rope consisting of Ultra Blue copolymer olefin fibers. The main difference between the two ropes is the manner in which they are braided. While the QS Polytron has a typical single braid construction that leaves a void in the center of the rope, the RP Ultra Blue offsets three of the strands that fill parts of the void in the center of the rope. This type of construction gives maximum wear life due to the firm, round flexibility of the rope. It has high strength and an elastic elongation of about 1.3% at 10% of breaking strength. Only three-fourths-inch diameter ropes were used in the snap loading tests because this is the smallest diameter that can be constructed with the RP Ultra Blue construction. Figure 2.7 shows a three-fourths-inch RP Ultra Blue rope with a three-inch eye splice and whip stitching.

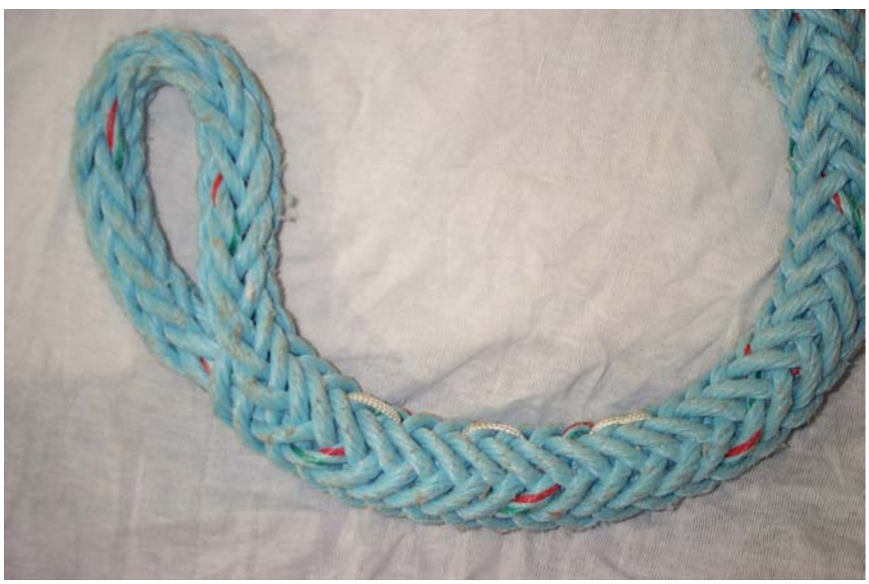

Figure 2.7 Round Plait Ultra Blue Synthetic Fiber Rope

2.3.7 Tenex

Tenex is a twelve-strand, Samthane coated, high tenacity, single-braided polyester rope that has high strength and low elasticity. Two of the more attractive qualities of this rope are its abrasion resistance and its ease of splicing. Tenex has an elastic elongation of about 1.4% at 10% of breaking strength. Full polyester ropes have slightly more elongation than other high modulus ropes. Tenex is very soft to the touch because all of the fibers are polyester. Three-eighths-inch and one-half-inch diameter ropes were used in the snap loading tests. Figure 2.8 shows a Tenex synthetic fiber rope with a three-inch eye splice and whip stitching.

Figure 2.8 Tenex Synthetic Fiber Rope

2.3.8 Round Plait SSR 1200

The Round Plait SSR 1200 rope has a compound yarn construction of polyester fiber on the outside and Ultra Blue fiber on the inside. This round plait construction uses an Ultra Blue inner strand fiber with polyester fibers wrapping around the inner strands. SSR 1200 has high strength and low stretch and is easy to splice. It has an elastic elongation of about 1.46% at 10% of breaking strength. Only three-fourths-inch diameter ropes were used in the snap loading tests because of construction limitations on diameter size. Figure 2.9 shows a Round Plait SSR 1200 rope with a three-inch eye splice and whip stitching.

Figure 2.9 Round Plait SSR 1200

2.3.9 Round Plait Polyester

Round Plait Polyester (RP Polyester) is a simple rope that consists of all polyester fibers in a single round plait braid. Like other ropes previously mentioned, this rope has high breaking strength with low elongation or stretch. The round plait construction allows for maximum surface area exposure and a tighter braid while being easy to splice. The wear life for this rope is superior to most others of the same construction. RP Polyester has the highest elongation percentage of all the ropes tested. Its elastic elongation is about 1.7% at 10% of breaking strength. Only three-fourths-inch diameter ropes were used in the snap loading tests because of the construction limitations on diameter size. Figure 2.10 shows a Round Plait Polyester rope with a three-inch eye splice and taped “loose” strands.

Figure 2.10 Round Plait Polyester Synthetic Fiber Rope

2.3.10 XLS Yacht Braid

The XLS Yacht Braid synthetic fiber rope has a double-braided construction that consists of a polyester core and cover. This rope has excellent strength with relatively low stretch. The elastic elongation for this rope is slightly higher than some of the other ropes that were tested because of the all-polyester construction. Only one seven-foot XLS Yacht Braid was tested under snap loading, and no nine-foot ropes of this kind were tested. The rope that was tested has a three-eighths-inch diameter core and a two-inch soft eye splice. The whip stitching for this double-braided rope is not the same as for the double-braided Amsteel II rope. This stitiching is the same type found in single-braided ropes because the rope diameter is so small. Figure 2.11 shows the XLS Yacht Braid synthetic fiber rope.

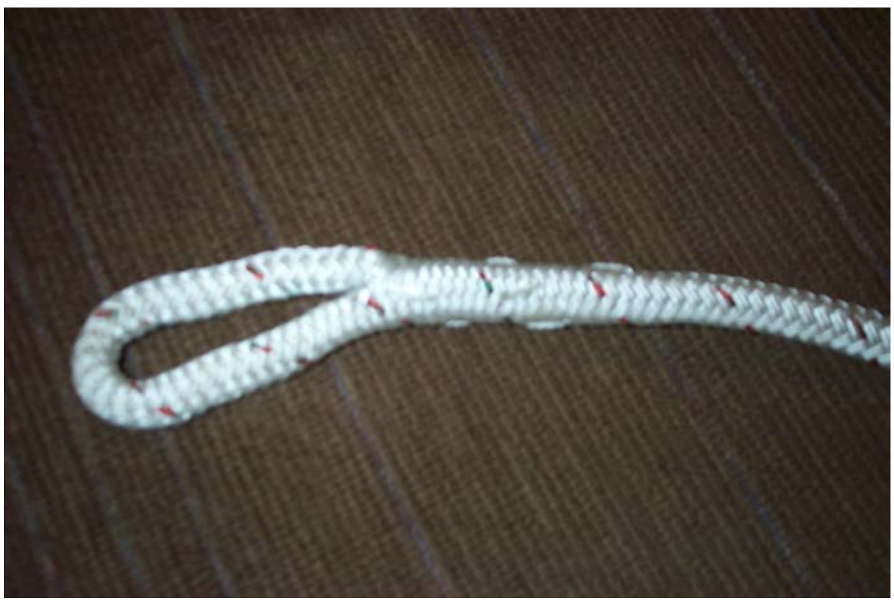

Figure 2.11 XLS Yacht Braid Synthetic Fiber Rope

2.3.11 Dura Plex

Dura Plex is a twelve-strand single-braided synthetic fiber rope that consists of polyester and olefin fibers. Polyester fibers are plied over olefin fibers to make composite strands that have an excellent strength-to-weight ratio. This rope is considered to be the easiest rope to splice that Samson Rope Technologies produces. Its elastic elongation is about 1.6% at 10% of breaking strength. Only one seven-foot Dura Plex rope was tested under snap loading, and no nine-foot ropes of this kind were tested. The rope that was tested has a three-eighths-inch diameter and a two-inch soft eye splice. Figure 2.12 shows the Dura Plex synthetic fiber rope with lock stitching.

Figure 2.12 Dura Plex Synthetic Fiber Rope