Spectra® and Plasma® Ropes

Introduction
Puget Sound Rope (PSR) began manufacturing high performance ropes of Honeywell’s Spectra® ultra-high molecular weight polyethylene (UHMWPE) fiber in the 1980s and is now the world’s leading supplier of single and double braided ropes using Spectra fiber. During this period of time, PSR and Honeywell have developed a long-term relationship focusing on technological developments designed to enhance the performance characteristics of Spectra® fiber in rope constructions and specific applications. Today, PSR’s Spectra and Plasma® ropes are utilized in numerous diverse applications around the world, providing excellent service and durability. However, recently there have been numerous statements made as to the performance properties of both Spectra fiber and Plasma ropes that are either incorrect or misleading. These claims are addressed in the following sections.

UHMWPE Fibers
There are two major manufacturers of UHMWPE fiber: Honeywell and DSM (Dutch State Mines). DSM patented the overall concept of high molecular weight polyethylene, but Honeywell, working under a license from DSM, was the first company to bring a commercially viable product (Spectra) to market. Production of Spectra fiber began in the early 1980s in the U.S. DSM’s Dyneema® fiber, manufactured in the Netherlands, followed at a later date. While there are some other manufacturers currently producing this type of fiber, most notably in China, Spectra and Dyneema are the primary UHMWPE fibers used in the production of rope.

There are several different types of Spectra and Dyneema fiber available, depending upon the intended application. For ropes, both Honeywell and DSM offer two primary grades of fiber. The Spectra fibers used most frequently in ropes are S-900 and S-1000, while the two most common grades of Dyneema are SK-60 and SK-75. S-1000 and SK-75 are higher in strength than S-900 and SK-60 respectively. The basic properties of each type of fiber are shown in the following table.
Table No.1: UHMWPE Fibers

<table>
<thead>
<tr>
<th></th>
<th>Honeywell</th>
<th>DSM</th>
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<tbody>
<tr>
<td></td>
<td>S-900</td>
<td>S-1000</td>
</tr>
<tr>
<td>Denier(^1)</td>
<td>4800</td>
<td>1300</td>
</tr>
<tr>
<td>Strength-gpd(^2)</td>
<td>25.5</td>
<td>35</td>
</tr>
<tr>
<td>Modulus-gpd</td>
<td>785</td>
<td>1150</td>
</tr>
<tr>
<td>Elongation-%</td>
<td>3.9</td>
<td>3.4</td>
</tr>
<tr>
<td>Denier/filament(^4)</td>
<td>10</td>
<td>5.4</td>
</tr>
</tbody>
</table>

Notes:
1. Denier is a measurement of the weight of the fiber per unit length expressed in grams.
2. Fiber strength is expressed as grams per denier (gpd). As an example, for the S-900 yarn the denier is 4800 and the strength is 25.5 grams per denier so the strength of the fiber is 4800 denier x 25.5 gpd = 122,400 grams or approximately 269.6 lbs.
3. DSM utilizes the procedures set forth in ISO 2062 to determine certain fiber properties including strength. Honeywell uses ASTM 2256. Each standard uses different methods of sample preparation and testing that can lead to results that cannot be duplicated using the other standard. The reported strength of SK-75 has not been verifiable using ASTM 2256.
4. Denier/filament is a measure of the size of the individual filaments comprising the fiber bundle. The larger the number the bigger the filament.

As the above table shows there is very little variation between the types of fiber with respect to their basic properties. In addition, both Spectra and Dyneema have the same specific gravity, coefficient of friction and chemical resistance properties. However, significant differences in manufacturing procedures have resulted in some variations between Spectra and Dyneema with respect to their physical characteristics and performance properties.

**Plasma Ropes**

In the mid-1990\(^{th}\), PSR developed a patented recrystallization process for converting Honeywell's S-900 fiber into a higher strength material. The Plasma process produced ropes that were the highest strength constructions available, predating the availability of ropes made from either S-1000 or SK-75. PSR's patented Plasma process involves realigning the molecular structure of the Spectra fiber under a combination of precisely controlled tension and elevated temperature. This procedure not only produces a stronger fiber but also ensures that all of the individual filaments within the rope component being processed are the same length, thereby maximizing fiber efficiency. In order to control the process with a high degree of precision, the Plasma process is carried out on a sub-component of the finished rope (i.e. a strand or other twisted component) rather than the entire rope.

One of the primary elements of the patent is the method used to heat all of the fiber filaments uniformly. This involves complete immersion of the manufactured rope component in a hot liquid bath. Synthetic fibers are poor conductors of heat. Consequently, the only way to make sure that all of the filaments are heated to the same
temperature is to use a hot liquid to penetrate throughout the fiber bundle. Any other type of heating will not produce the desired results.

**Heat-Set Ropes**
Since its development, Plasma has been extremely popular in a wide variety of applications due to its durability and strength. In recent years, other rope manufacturers have attempted to duplicate the results obtained from the Plasma process by utilizing a heat setting technique. However, heat-set ropes are produced by running a strand or rope under load through a forced hot air oven, not the liquid bath that is a key part of the Plasma patent. The hot air heats up the surface of the rope but, because of the poor thermal conductivity of synthetic fibers, the interior of the rope does not reach the same temperature. Consequently, this type of process is only partially successful at best. There is some increase in initial strength, but this is due primarily to the high loads used to process the rope. This load in effect work-hardens the rope, not unlike the initial increase in strength obtained from a new rope if it is tensioned repeatedly for several cycles. However, the uneven heating also produces a rope with unequal fiber lengths throughout the rope's cross-section because the interior of the rope will not be heated sufficiently. This produces uneven load sharing throughout the rope's cross-section that will adversely affect the rope's strength efficiency and overall performance. In conventional double-twist braided ropes, especially in the larger sizes, there is already an inherent imbalance between the outer yarns in the strand and those in the interior. Heat setting of the rope can make this imbalance more pronounced. Another byproduct of this process is a stiffening of the rope structure due to the high loads placed on the rope combined with the hardening effects of the dry heat. It is important to note that Plasma ropes are not heat-set and do not exhibit any of the adverse performance properties associated with this type of procedure.

**Performance Properties**
Although the last ten years have proven the durability and excellent performance of Spectra fiber and Plasma ropes in a diverse range of applications throughout the world, other rope manufacturers, specifically those using SK-75, have claimed that Spectra fiber and/or Plasma ropes have inferior performance properties. Generally, some sort of laboratory testing is used in support of these claims, completely ignoring the proven track record of Spectra and Plasma in all sorts of actual operations. Ironically, at the same time many of these manufacturers have begun producing heat-set ropes of their own in an attempt to duplicate the Plasma process. Some of the specific claims are addressed in the following sections:

A. **Creep:** Creep is the non-recoverable extension of a fiber over time due to a sustained load. If the load is held for a sufficient length of time, the fiber will fail. As a class, UHMWPE fibers are susceptible to creep failure; however, Dyneema is somewhat more resistant to creep than Spectra. The following graph illustrates the differences between the two brands of fibers. It should be noted that Plasma is not included in this graph because the Plasma process does not produce a fiber but rather a completed rope component.
Although DSM has aggressively promoted the higher creep resistance of Dyneema fiber, creep is basically of little or no concern in most applications in which UHMWPE ropes are used. This would include uses such as mooring lines, ship assist lines, winch lines, etc. Failure of UHMWPE ropes in these types of applications is primarily due to a combination of wear (abrasion, cutting, etc.) and fiber fatigue, not creep. There are no documented instances of failure of a UHMWPE rope in these types of service that can be attributed to a creep rupture.

Reliance on published creep data can also be misleading because most of this testing has been done on either the fiber itself or very small braids or twines. However, as rope size goes up the efficiency of the rope structure goes down. In a large rope the overall efficiency may be around 50%, meaning that only 50% of the total strength of the fiber is being fully utilized. This drop-off in efficiency is not a reflection on the quality of the rope; rather it is a natural consequence of the manufacturing process. In order to determine what affect a particular load may have on a rope it is necessary to take this decrease in efficiency into consideration in order to estimate what the load on the fiber is. Only then can published creep data be used with any accuracy to determine what affect a sustained load may have on a rope’s strength.

As an example, PSR recently completed a 3-year long creep test on 7/16-in. dia. Spectra 12-strand ropes. The new breaking strength of the rope was tested at 19,400 lbs. Spliced test samples were then hung in series with a dead weight load of 3,346 lbs., representing approximately 22.4% of the published minimum strength and 17.2% of the actual strength. A gage length was marked out on each sample prior to the start of the test. This gage length was measured while the samples were under a base reference load of approximately 30 lbs. and then again after the 3,346-lb. load
was applied. Then, at periodic intervals selected samples were measured and then removed and pulled to destruction. The results of this test are given below:

Table No.2: PSR 3-YR. Creep Test Results

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<tr>
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<tbody>
<tr>
<td>Start</td>
<td>---</td>
<td>---</td>
<td>19,400</td>
<td>---</td>
</tr>
<tr>
<td>Start</td>
<td>30</td>
<td>6.00*</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Start</td>
<td>3,346</td>
<td>6.25*</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>10</td>
<td>3,346</td>
<td>6.25</td>
<td>20,750</td>
<td>2%</td>
</tr>
<tr>
<td>20</td>
<td>3,346</td>
<td>6.375</td>
<td>20,600</td>
<td>4%</td>
</tr>
<tr>
<td>30</td>
<td>3,346</td>
<td>6.5</td>
<td>20,150</td>
<td>6%</td>
</tr>
<tr>
<td>60</td>
<td>3,346</td>
<td>6.625</td>
<td>20,950</td>
<td>8%</td>
</tr>
<tr>
<td>180</td>
<td>3,346</td>
<td>6.75</td>
<td>20,600</td>
<td>10%</td>
</tr>
<tr>
<td>1100</td>
<td>3,346</td>
<td>8</td>
<td>18,000</td>
<td>28%</td>
</tr>
</tbody>
</table>

*The initial difference in the gage lengths is due to constructional stretch as the rope was placed under the higher load.

Comparing these results with the creep of S-900 at 15% load in Fig. No.1, it can be seen that the creep experienced by the rope for a given period of time was less than ½ that of the fiber under a similar load. It is also important to note that, even after three years, the rope retained about 93% of its original strength. In affect, the creep experienced by the rope had virtually no affect on its strength or durability.

An independent firm has also tested Plasma and Dyneema ropes to determine creep properties at elevated loads. These two tests are shown in the following figures:
As the graphs show, the creep of Plasma ropes at elevated loads is not very different from that of ropes made from SK-75. Consequently, even though creep is usually not a factor in most standard operations it would be incorrect to state that Plasma is inherently more prone to creep than SK-75.

B. Abrasion: While there are some standardized tests for yarn-on-yarn abrasion (Cordage Institute Test Standard 1503, etc.), there are no established procedures for testing the abrasion resistance of ropes. Claims of superior abrasion resistance, especially for large rope sizes, are not supported by any sort of approved or universally accepted test procedure. Consequently, most manufacturers have developed their own methods of testing for abrasion resistance. Again, much of this work has been done on very small braids or twines and, in many cases, the results seem to be contradictory or misleading. DSM has performed some tests in which 8 mm (5/16-in. dia.) braids of S-900, SK-60 and SK-75 were bent through 90° around a rotating wheel. The twines were placed under a load of 930 kg (~2,050 lbs.) and the wheel rotated until failure of the sample occurred. The results of this test are shown in the following figure:

**Figure No.4: Abrasion of Small Braids**

![Figure No.4: Abrasion of Small Braids](image)
This test is basically meaningless in that the test conditions are too severe to yield any reliable, repeatable information on durability or comparative fiber performance. Furthermore, testing an SK-75 construction under the same load as that used for the lower strength fibers gives a misleading impression that SK-75 is significantly better in abrasion than either Spectra or SK-60.

Honeywell has carried out tests on both fiber and twisted yarns. The fiber tests were conducted in accordance with established Cordage Institute test procedures. The fiber test results are shown in the following figure:

![Figure No.5: Yarn on Yarn Abrasion](image1)

Twisted yarns were also placed under load and passed back and forth over a steel hex bar for 500 cycles. The yarns were then broken and the resulting strength compared to new yarns of the same composition and twist. Both variants of Spectra retained a higher percentage of their new strength than the corresponding Dyneema fibers. The results are shown in the figure below:

![Figure No.6: Yarn Abrasion on Hexbar](image2)
Both of these tests are much more realistic than the DSM test procedure in that they more closely approximate real-world conditions. However, in large ropes abrasion is just as much a function of rope construction and other factors as it is of yarn properties. Therefore, it is misleading to say that one type of fiber is inherently more abrasion-resistant than another. It should be noted that one possible reason for the improved abrasion resistance of both S-900 and S-1000 in the fiber and small yarn tests is the larger size of the filaments that make up the fiber bundle. As explained in the chart of comparative fiber properties above, S-900 filaments are about ten times larger than the filaments making up SK-60, while the filament size of S-1000 fiber is 2.5 times larger than that of SK-75. The finer the filament the more it may be susceptible to abrasion damage.

C. **Bending Fatigue:** Very little bend fatigue testing has been carried out by the rope industry and/or fiber manufacturers on UHMWPE ropes, especially in the larger sizes. As with abrasion testing there are no standardized test procedures for gauging the resistance to bending fatigue. Again, DSM has utilized their own test procedure to test very small braids of approximately 1/8-in. dia. These small twines were placed under a very high load and then cycled through a series of three sheaves to produce a reverse bending configuration. Like the DSM abrasion test, the bending fatigue test procedure is much too severe to yield any meaningful information. Also, the results for the SK-75 rope shown below cannot be compared directly with the S-900 or SK-60 results because the load that was used in the test is a much smaller percentage of the SK-75 rope's breaking strength.

**Figure No.7: Reverse Bending**

![Figure No.7: Reverse Bending](image)

DSM has also conducted some bend over sheave tests on small ropes of different constructions and fibers. The ropes were tested over a sheave with a root diameter of ten times the rope diameter. Tests were run at different loads and the number of cycles to failure plotted. As shown in the figure below, 12-strand braids of S-900 and
SK-60 were fairly equal in performance at lower load levels. At higher loads DSM reported that the SK-60 fiber performed better than the S-900. Again, the results for SK-75 can't be used to make direct comparisons with either the S-900 or the SK-60 because the same load was used to test all of the samples.

Unlike other rope companies, PSR has been actively engaged in bending fatigue testing for several years as part of an ongoing commitment to research and development. And, unlike the tests reported above, PSR has focused on testing large ropes in order to approximate as closely as possible real world conditions.

Current in-house testing by PSR is a continuation of a program that was initially started by a major offshore seismic contractor. This company wanted to improve the performance of the UHMWPE ropes that were being used to tow the seismic arrays. It was felt that the ram tensioners and sheaves used to compensate for vessel movements were causing premature failure of the ropes as they worked back and forth over the sheaves while under considerable tension. The seismic contractor devised a test program that simulated the actual conditions encountered offshore as closely as possible. In addition, it was decided to test full-sized ropes because it was felt that test results on small braids were not representative of the performance of larger constructions and could not be scaled up with any degree of confidence. Consequently, all testing was performed on 6-in. circ. UHMWPE ropes.

Prior to PSR's involvement, all the samples tested were made using Dyneema SK-75. Many different manufacturers, mostly from Europe, supplied samples. The test procedure involved tensioning a sample to a specific load and then cycling it back and forth over large diameter sheaves until the rope failed. The surface temperature and overall elongation of each sample was constantly monitored and recorded during the test.
After the initial phase of testing, PSR put together a Joint Industry Program (JIP) involving the original seismic contractor along with other operators in the offshore seismic industry. The stated goal of the JIP was to develop an improved rope construction that would increase bending fatigue resistance. Since PSR had not supplied samples during the initial round of testing, PSR first tested a Plasma 12 x 12 rope for comparative purposes. The results of the first phase of testing are shown in the following figure:

The samples identified as SK75-1 through SK75-13 are all SK-75 12-strand braids. The manufacturer of each sample was not identified and particulars about constructions, coatings and other manufacturing specifications are not known. The only two Plasma tests conducted during this phase are shown at the right-hand side of the graph. These samples were PSR’s patented 12 x 12 strand construction. The performance of the first sample (Plasma1) was comparable to several of the better performing SK-75 samples. A subsequent Plasma sample was later tested with a different type of coating and slight constructional changes. This sample achieved 4,000 cycles, exceeding the best SK-75 sample by a considerable margin.

These results dispel the claim that SK-75 is more durable in bending fatigue resistance than Plasma. The test results also illustrate another factor that is not addressed by DSM and the various rope manufacturers that have made this claim. As the above graph shows the quality of the rope construction itself has a significant impact on durability. The best SK-75 sample performed about four times better than the worst one, yet all of the samples were 12-strand braids made from SK-75. Furthermore, the Plasma 12 x 12 construction with the improved construction outperformed the best 12-strand SK-75 rope by about 33%. Obviously, the type and quality of the construction can play a significant role in the overall performance of the rope.

D. Tension-tension fatigue: One of the most publicized statements by other rope manufacturers is the claimed superiority of SK-75 ropes in resisting tension-tension fatigue. The procedure used to support this claim is known as the Thousand Cycle Load Level (TCLL) test. In this test a rope is cycled 1000 times from a base
reference load to 50% of its break strength. If the rope survives it is then cycled to 60% of its breaking strength for another 1000 cycles. The procedure continues in 1000-cycle intervals at 10% incremental increases in the load until failure occurs. The results are then used in a formula to calculate a TCLL value that theoretically represents the load (expressed as a percent of the breaking strength) at which the rope would fail at exactly 1000 cycles. While the calculated TCLL value may not, in actual fact, be that accurate with respect to the exact number of cycles required to break a rope, a comparison of the TCLL values for different ropes and/or fibers is considered a good indicator of the relative durability of a fiber and rope construction to cyclic tension-tension fatigue.

Samson carried out this test procedure on 4-in. circ. AmSteel Blue and Plasma 12-strand ropes. The AmSteel Blue sample failed during the cycling procedure at the 90% load level and the Plasma sample failed during the cycling procedure at the 70% load level. Using the procedure described above, the calculated TCLL value for the AmSteel Blue sample was approximately 83% while the Plasma TCLL value was around 67%. While the validity of the test is not in question, PSR felt that the results reported for the Plasma sample did not reflect the true durability of the Plasma construction. PSR therefore decided to carry out its own TCLL test to see if the results on Plasma could be duplicated.

A sample of 6-in. circ. Plasma 12 x 12 was subjected to the TCLL test. The rope survived until the 92nd cycle at a load level of 100%. The formula used to calculate the TCLL value is not designed to work with load levels of 100% so the resulting TCLL value for the Plasma rope is basically off the chart. This result proves that Plasma braided ropes are extremely durable and highly resistant to tension-tension fatigue and refutes the claim that SK-75 ropes are inherently superior.

Conclusion
Puget Sound Rope has been producing ropes manufactured from Spectra fiber for many years. These products, most notably Plasma 12-strand and 12 x 12 ropes, have been used successfully in numerous diverse, rigorous applications throughout the world. The excellent performance of these ropes has never been questioned by the end-user. Claims and/or misleading statements by DSM and several competing rope manufacturers of inferior performance properties cannot be substantiated on the basis of questionable lab tests that have little bearing on real-world applications.

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1 DSM technical literature
2 Honeywell International technical literature
3 PSR in-house test data
5 PSR-Seismic Industry JIP 2001