S.I.O. REFERENCE SERIES

NUMBER: 92-33

IMPROVED FATIGUE LIFE FOR MOORINGS

Richard J. Seymour & Samuel A. Massey

Marine Research Division, 0222

California Sea Grant College Program

December 1992

UNIVERSITY OF CALIFORNIA, SAN DIEGO

Improved Fatigue Life for Moorings

University of California, San Diego

R/OE-14

1990-92

Richard J. Seymour and Samuel A. Massey

Introduction

Moorings are ubiquitous in man's useful occupation of the ocean. They are used to secure instruments and other unattended apparatus for scientific, civil and military uses and to fix the location for various lengths of time of manned platforms for mineral and hydrocarbon extraction and for marine transportation and ocean construction applications. Subject to wave and current loads, vibration from eddy shedding, and a hostile chemical environment, moorings fatigue and eventually fail if not replaced in time.

This research is directed toward significantly improving the reliability and the service life of ocean mooring systems by developing the use of nonconventional materials (particularly advanced composites) and constructions. The work will extend previous and present research by the investigators in highly related areas. Subscale mooring elements (lines, terminations, and flexures) will be tested for fatigue resistance in a seawater environment in the laboratory.

The overall project objective is to make substantial improvements in the service life and reliability of ocean moorings by using materials and constructions that are significantly less sensitive to fatigue and stress corrosion than conventional components.

This research follows from an initial NSF grant that led to the development of a promising material construction and its associated manufacturing processes. This construction consists of composite "wires" of continuous graphite fiber reinforcement in a matrix of Du Pont J-2 thermoplastic resin. Seven of the individual wires are then warm-formed (at a temperature high enough to allow deformation of the matrix without melting) into a twisted cable. This cable, in which the individual wires are free to slide over their neighbors, has a useful bending radius no greater than that of one wire, although it has potentially seven times the strength.

In our original proposal we intended to utilize Kevlar as well as graphite as reinforcements in the tethers. We have found that the Kevlar material does not process in a satisfactory manner in the fabrication of the individual wires. The raw material tends to ball at the entrance to the die, eventually causing the strand to fail. We therefore decided to concentrate all of our efforts on the more difficult problem of terminating the graphite strands because the graphite offers much greater strength/weight characteristics and has the potential for significant improvements in fatigue strength. A detailed description of the manufacturing and testing processes follows.

Wire Pulling:

The composite wire for this project was manufactured by pulling continuous graphite fiber reinforcement and Du Pont J-2 thermoplastic resin through a hot die. This was accomplished in our lab on a custom-built device consisting of a tow rack, pultrusion oven and take-up wheel. A schematic of the setup is shown to the right in Fig. 1.

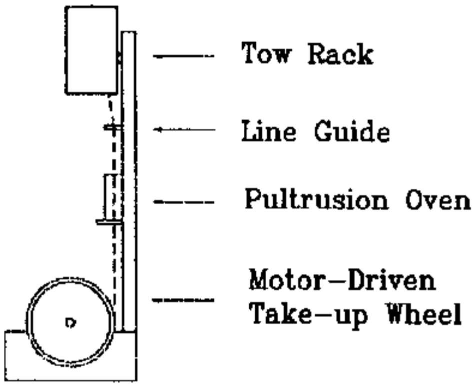

Fig. 1: Wire Pulling Configuration.

Material for manufacturing the carbon composite wire was supplied by Du Pont. It consists of five tows with approximately one pound of a carbon fiber and J-2 thermoplastic resin mixture on each. The material is pulled directly from the tows in a special rack included in the wire pulling setup. Tow placement in the rack is designed to produce a minimum bending angle on the carbon fibers. The rack gives a lightly tensioned independent material supply from each tow.

The oven used for manufacturing the carbon composite wire is a small, well insulated electric oven setup to support a die and fitted with a thermocouple for thermostat control. The die used in this oven consisted of a 6 to 8 inch length of stainless steel tubing (0.125" O.D. and 0.054" I.D.) which was flared at one end. An enlarged diagram of the pultrusion oven setup is shown in Fig. 2.

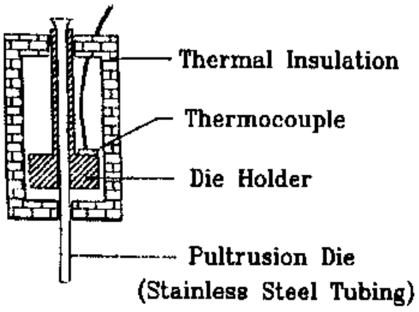

Fig. 2: Pultrusion Oven.

The wheel on this device has a lip on one side to guide the wire to its center and tapers from the center outward on the other side. This is to allow wire to slip off easily as it is pushed aside by wire being pulled, as shown in Fig. 3. The wheel is driven by a variable speed motor that was calibrated to pull wire at speeds from 0.8 in/min to 4.0 in/min.

Fig. 3: Puller wheel contour.

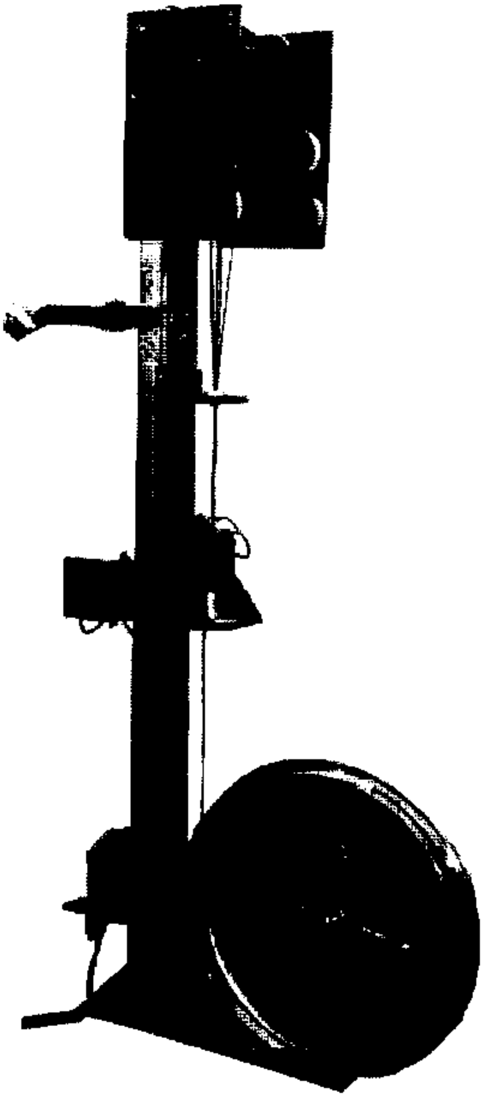

Fig. 4: Actual Wire Pultrusion Setup.

Once the spools are mounted in the rack and the device is setup as shown in Fig. 4, wire pulling is started by pulling strands from two tows through the line guide and the die. They are securely fastened to the pulling wheel near the outside edge with masking tape. The pulling wheel is then set to 2 in/min and turned on. This is done by setting the master control at 50 and the puller control at 44 on the respective dials and turning the power on.

Once the puller is moving, the oven must be slowly brought up to the melting temperature for J-2. It is set to 100°C and allowed to reach a peak temperature (about 150°C). The thermostat is then gradually increased to a final setting of 300°C. The gradual increase keeps the overshoot of the final temperature to a minimum. When the final temperature of 300°C is achieved additional strands are gradually added between existing strands until the material from all five tows is being pulled through the die. Once this is achieved the wire is marked to identify the beginning of the desired material and three take-up hooks are taped in place on the take-up wheel to hold excess wire in place for later collection.

The puller must be periodically checked and excess wire removed as it builds up on the wheel (every 50 or so turns). Care should be taken to keep the two or three wraps closest to the center of the wheel tight so that pulling continues. The puller is run until either enough wire is pulled or the die jams (resulting in a broken wire). In the event of a die jam, the die must be replaced before a new run is started.

Cable Twisting:

Wires are twisted into cables by modifying the pultrusion device. A separate variable speed motor is added to turn a guide, twisting the wires as they enter the oven. In the oven they are heated to the plasticity point for J-2 (oven to 175°C) to set the twist and form a cable. The same take-up wheel is used for this procedure. A schematic of the twisting setup is shown in Fig. 5.

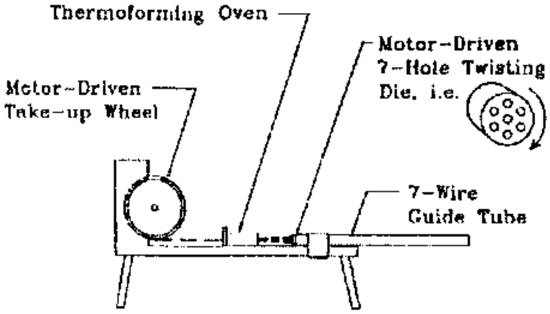

Fig. 5: Cable Twisting Configuration.

The motorized wire guide consists of an aluminum tube (threaded on one end) mounted on two bearings with a chain drive. It is calibrated for speeds between 0.4 RPM and 2.0 RPM. A seven-hole die secured in the threaded end of the guide twists the wires, as shown above in Fig. 5. This process utilizes the same oven used for pultrusion, but without the die. The wires are simply suspended through the oven between the die and take-up wheel. The actual setup is shown in Fig. 6.

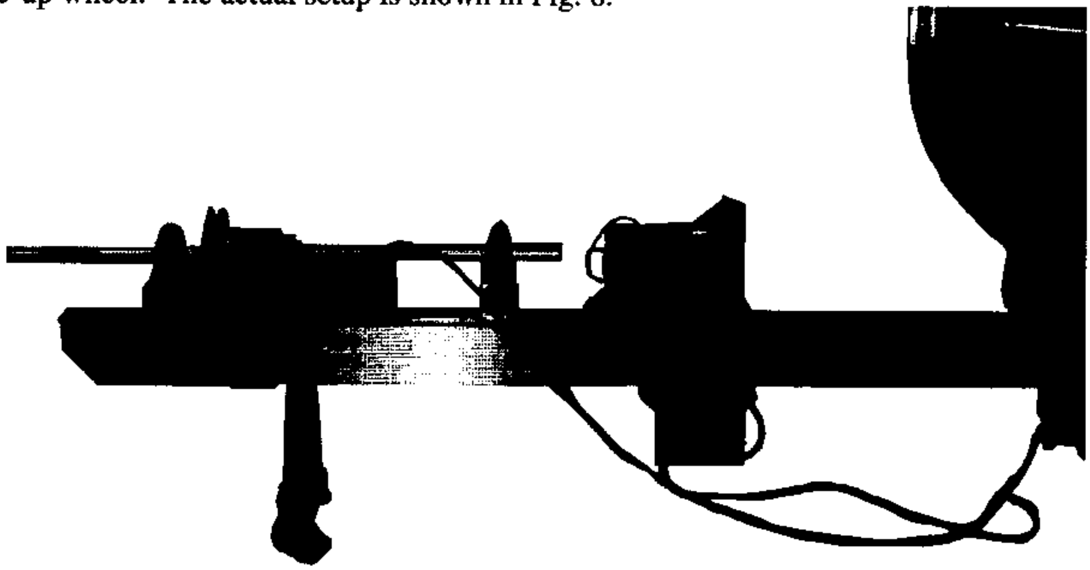

Fig. 6: Actual Cable Twisting Setup.

The current six wires wrapped around one arrangement requires that seven wires be fed into the twister. These wires must be free to twist with the twister prior to reaching it. To accomplish this in the lab space available, lengths of wire 45' maximum are laid out down a hall in front of the twisting device. They are individually fed through the twisting guide and fed through the die. Once all seven strands are through the die it is secured in the end of the twister guide. Next the strands are pulled through the oven and secured near the edge of the pulling wheel with masking tape.

Once this is all in place the oven is plugged in and slowly heated to a final setting of 175°C. The temperature has to be carefully controlled because if the plastic gets too hot, the wires weld together. The puller is then set to pull the wire at 2.75 in/min and twist at 0.35 RPM resulting in approximately 1.5 turns per foot of cable. This is accomplished by setting the master control at 50, the puller control at 50, and the twister control at 30.

Care must be taken during the twisting process to continuously hand twist the wires behind the twister as it turns. This is to keep them from becoming tangled or twisted up behind the guide. Failure to keep the wires free from tangles as they enter the guide results in irregularities in the cable strand.

Progress Made:

For this project there were four major goals. The primary goal was to develop efficient termination techniques (i.e. end fittings) for the existing 7-wire twisted graphite strand. The second goal, pursued in parallel with the first, was to develop a fatigue machine for testing the resulting strand/termination system. The third was to develop fatigue-resistant swivels to allow for 2-degrees of freedom motion of the tethers. The fourth was to begin the fatigue testing.

The first goal addresses a problem common to most composite structures loaded primarily in tension. That is, it is characteristically difficult to utilize the strength of the structure effectively because of limitations on the strength of the transition from the composite to some metal fitting. This fitting is often necessary in order to transition to another construction or to allow for replacement, etc. It is usually difficult to terminate a rope without degradation of the basic strength. With graphite, because of its very great strength and stiffness, the problems are increased. It is impossible to bend the rope around a small radius and it is difficult, given the extreme stiffness of the material, to balance the load between all of the strands within the rope. As opposed to very elastic materials like Kevlar, graphite presents serious load sharing problems because it does not stretch very far before it breaks. Several types of industrial cable termination methods have been attempted and have been found to be inefficient when used on the graphite strand. A completely new method of termination which melts the strand matrix in a plug-and-socket end-fitting has been developed over the last year and has performed well. A custom-designed oven for thermoforming cable terminations was built to support these experiments. Following the recommendations of Dr. Francis Liu at NCEL, we have improved the load sharing between wires by pre-tensioning each wire as the termination is made. The fitting along with added J2 material is then heated in an oven and the tapered plug pushed down until the wires are deformed into a solid ring filling the annulus between the plug and the socket.

We have employed other novel termination methods, including resistive heating, but have found that they do not improve the thermoforming parameters achieved in the present method, which is detailed below.

Termination Seating:

A unique termination process is used for these cables. In order to insure that the load is distributed it is necessary to pretension each of the load bearing (outer) wires as they are seated in the terminations. This keeps the stretch required by the individual wires for load sharing to a minimum.

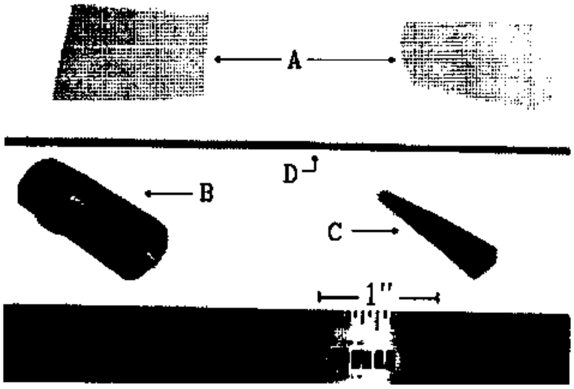

Fig 7: Termination Parts (A: 3-mil J-2 inserts B: Estmet sleeve C: Tapered plug D: Single composite wire).

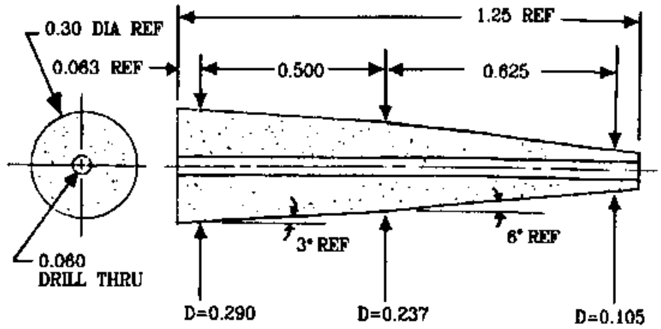

Fig. 8: Custom Plug Drawing.

Terminations for these cables consisted of added J-2, a tapered sleeve and a tapered plug, as seen in Figure 7. The sleeve was purchased from Estmet, Inc. part no. ID-925-N-M50503/16. It is a steel sleeve tapered on the inside and threaded 9/16-18 on the outside. The plug was machined from the drawing in Fig. 8. It was designed to match the taper in the sleeve for the first half inch. An assembly diagram of the termination is shown below in Fig. 9.

The pultrusion frame is again employed in cable termination. This time it is securely fastened to the floor and fitted with a larger oven. A plug seating weight rack and custom pulley rack bolted to the ceiling are also employed. A schematic is shown below in Fig. 10.

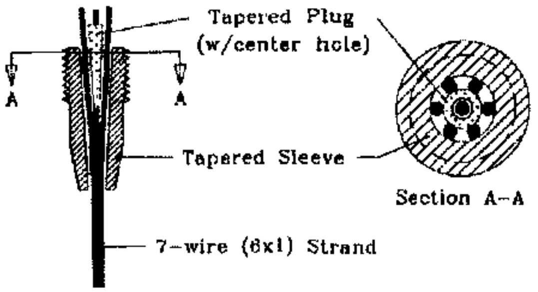

Fig. 9: Cable Termination.

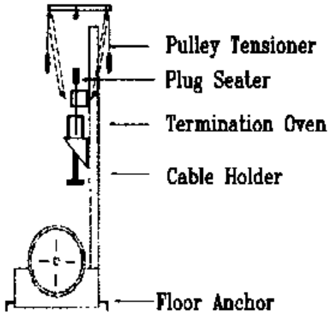

Fig. 10: Termination Setup.

The larger oven used here is also electric and uses the same thermostat control. It is hinged and opens from the side to allow for plug positioning. It has a 1.25 inch opening in top for the tensioned wires to exit and a 0.25 inch hole in the bottom to support the termination while allowing the cable to slip through.

The plug seating device consists of two pieces. A supported tube guide bolts above the oven. A smaller tube with a weight shelf slides through the guide, into the center of the oven. This provides a controlled seating pressure for the plug while it is melted into the sleeve with the wires in tension.

The pulley rack consists of six sets of three pulleys arranged on a circular board. Each set consists of two double pulleys and a single as shown in Fig 11. With a 20 lb. weight this system places 100 lb. tension on each wire.

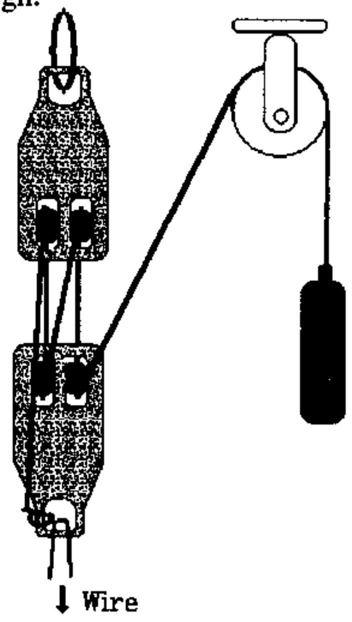

Fig. 11: Pulley Tensioning Setup.

Composite cable is cut for termination with 18 inches of overhang on each end. This is to allow for tensioning of each individual wire during the termination process. The sleeve is then slipped over the end of the cut cable and positioned. The center strand is then identified and the custom plug is slipped over it, but not into the sleeve, as shown in fig. 12a.

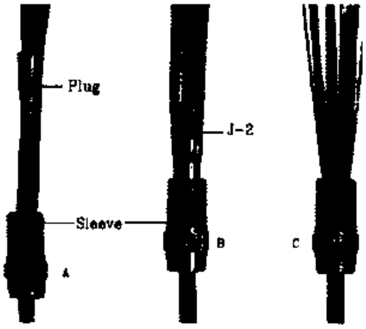

Fig. 12: Termination Assembly (A: Plug and sleeve, B: Termination assembled, C: Termination after seating).

In preparation for termination seating two pieces of J-2 are cut from a 3-mil thick sheet, as seen in Fig. 7a. One piece is wrapped around the custom plug inside the cable wires. The second is wrapped inside the sleeve outside the cable wires. The plug is than slipped down into the sleeve with the wires evenly spaced around it as shown in Fig. 12b.

If this is the first termination on a tether the opposite end must also have a fastener so it can be securely anchored for tensioning. This is accomplished by placing a temporary fastener (also purchased from Estmet) two inches below where the actual termination will later be placed. This fastener consists of a tapered cone (Sleeve #KA 918) and split plug (Plug #MA 3818) as shown in Fig. 13.

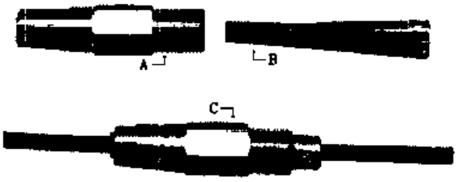

Fig. 13: Temporary Fastener (A: tapered cone B: split plug C: fastener attached to cable).

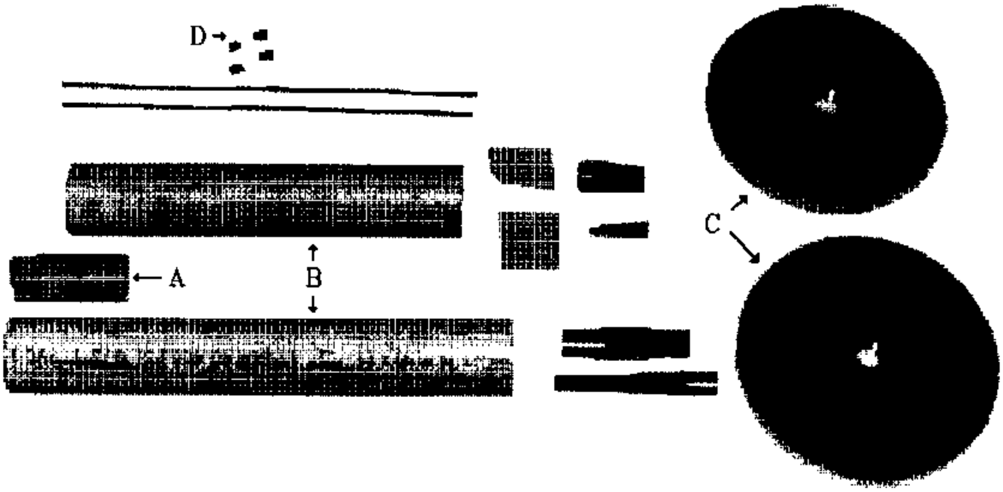

Fig. 14: Cable Restraining Parts (A: PVC pipe centering aide, B: lengths of PVC pipe, C: discs with threaded holes, D: leaderline sleeves).

In preparation for the tensioning of each wire, a leaderline sleeve (Seven Strand Leaderline Sleeve #A5 or #A4, part D in Fig. 14) is crimped onto each wire above the termination, approximately four inches from the clipped end. Once the termination is in the oven, a small nylon cord is then run through the eye of one of the double pulleys and tied to the wire using interlocking half hitches above and below the sleeve, as shown in Fig. 15. This is repeated for each of the load-bearing wires in the cable.

Fig. 15: Tensioning(A: leaderline sleeve crimped onto wire, B: half-hitch).

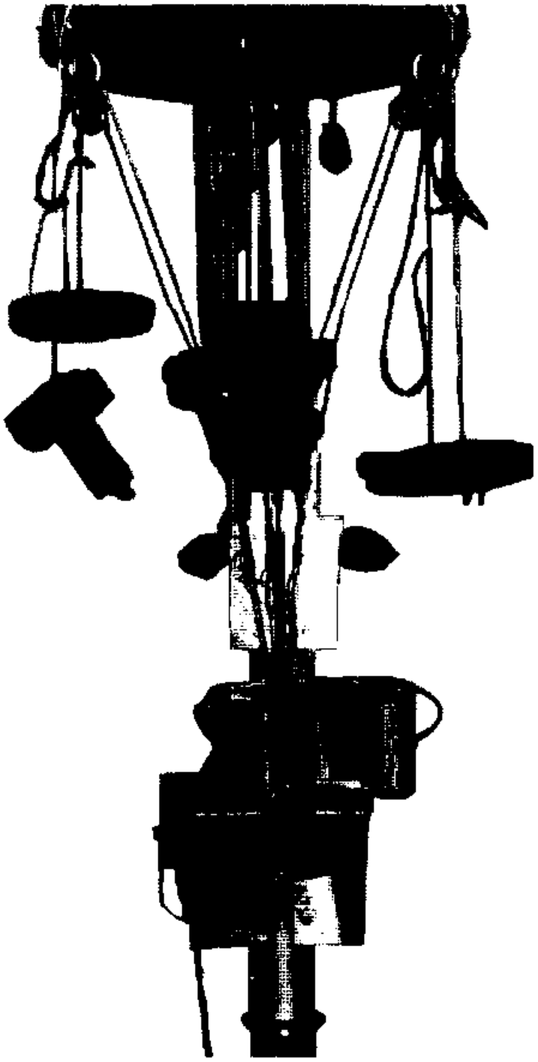

Fig. 16: Actual Termination Seating Setup.

Once each of the wires is attached to the pulley system, the plug seating rod is placed over the center wire and down onto the plug in the center of the oven. A PVC centering piece is then put in place at the bottom of the oven and the PVC pipe is slipped over the bottom end of the cable. The longer PVC pipe is used for the temporary fastener. The shorter one is for seating the second termination to finish a 14.5" tether. It is followed by the appropriate retaining ring which is screwed into place securing the bottom end of the cable. The actual termination sleeve and temporary fastener have different threads, so two retaining rings are needed. The PVC parts and retaining rings are shown individually in Fig. 14.

Weights are placed on the plug seating rod totaling 25 lbs. Then the slack is removed from each pulley system. Once all are tight, 20 lb. weights are placed on each system resulting in approximately 100 lb. tension force on each wire. Each pulley system is then tugged slightly to verify that the wires are loaded equally. The setup at this point is shown in Fig. 16.

Next the oven is closed and raised to 300°C. The termination is left in the oven at this temperature for 15 minutes. Then the oven is turned off and allowed to cool. Once it has cooled sufficiently, the weights are removed.

Once the termination is removed from the oven it is as shown in Fig. 12C. It is finished and ready to use after the remaining pieces of wire are broken off the threaded end. This process is also used to produce parallel tethers from untwisted wires. Several tethers terminated on each end in this fashion, measuring 14.5" end to end, were manufactured for tensile and fatigue testing.

Tensile Testing:

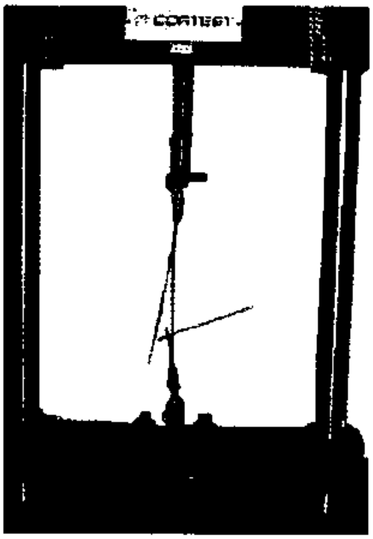

Fig. 17A: Fractured tether in tensile tester.

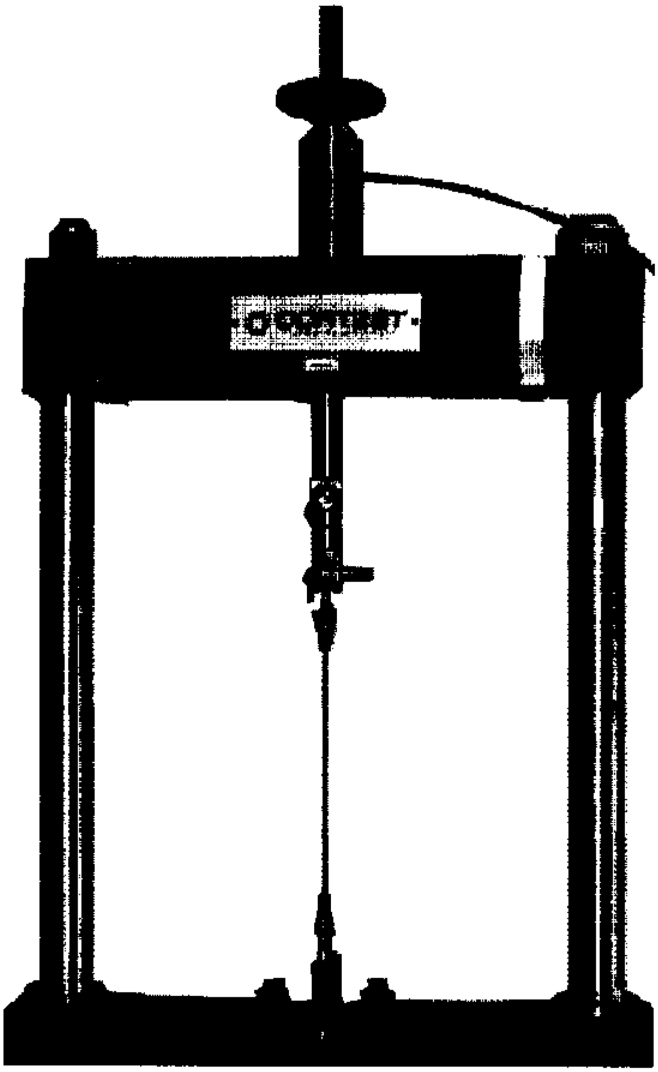

Fig. 17B: Tether in tensile tester.

Tensile testing of wires was done on a computer-driven CorTest tensile tester fitted with a 1 kip load cell. Individual wires were potted in epoxy and pulled to fracture. Tests of 3 individual wires produced an average breaking point of 500 lb. Since the wire diameter is approx 0.05" this is an average ultimate tensile strength of 250 ksi.

Tensile testing of terminated cables was done on the same computer driven CorTest tensile tester fitted with a 10 kip load cell. Terminated tethers were loaded in the tester as shown in Fig. 17. Loading of up to 2.2 klb was achieved. Since this is for 6 load-bearing wires of 0.05", this is an average maximum stress of 187 ksi, 73% of the estimated average cable strength.

Fatigue Tester:

The second major task of this project was the development of a heavy-duty fatigue machine for testing the strength of the strands and their terminations. This unit is required to provide simultaneously a large constant tensile load and a smaller load component that is applied and removed once per second to simulate wave loading. This condition of rapidly changing loads is called fatigue loading and typically results in failures after many thousands (or millions) of cycles at loads far below the load that fails the component upon a single application. In metals, this fatigue mechanism results from the propagation of microcracks within the metal. Very little is known about tensile fatigue in graphite reinforced plastics. We expect, therefore, to examine the stressed tethers in detail to determine what we can about failure modes. The main thrust of this program is to increase the resistance of moorings to fatigue loading, so this testing capability is critical.

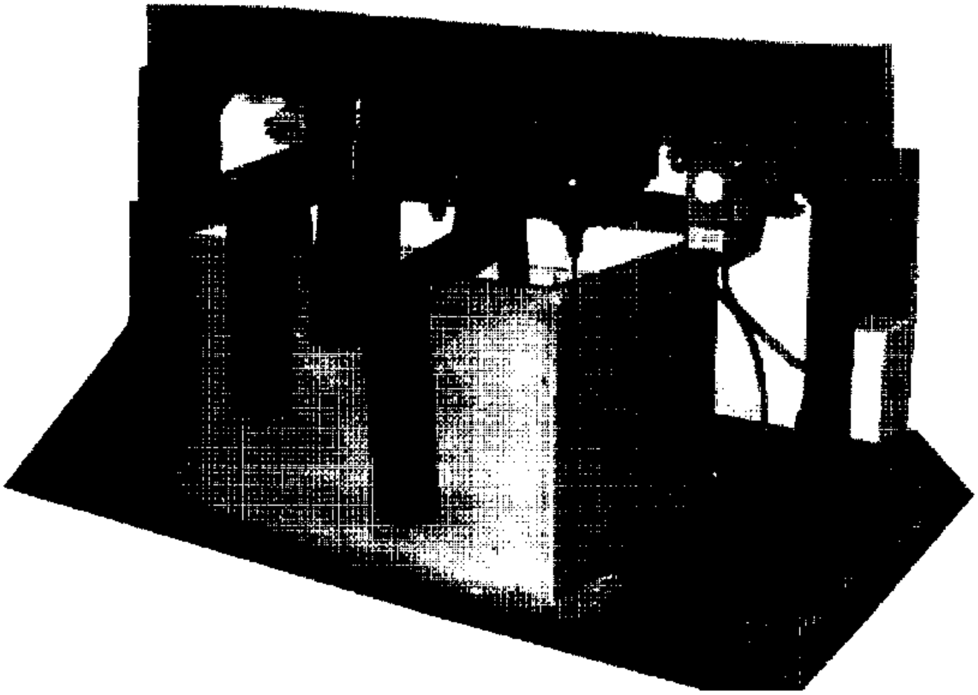

Fig. 18a: Custom-built fatigue tester with large weights.

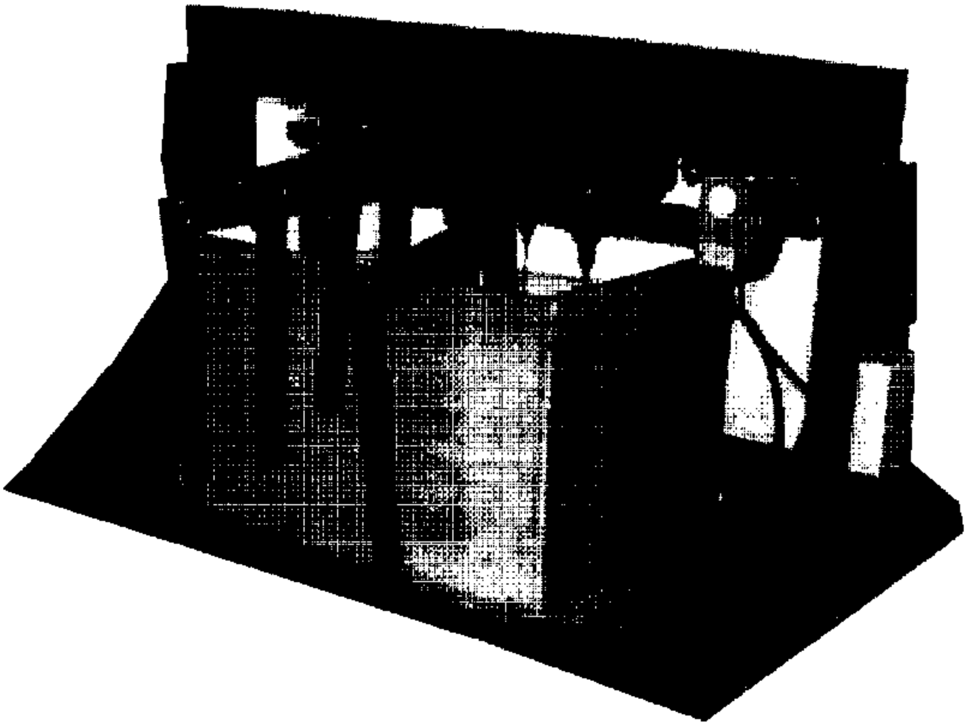

Fig. 18b: Custom-built fatigue tester with small weights.

The fatigue strength is typically reduced drastically in harsh environments, including sea water. Therefore, provision must be made to subject the tethers to fresh flowing sea water during their testing, which could require periods of months to more than a year.

Fatigue testing of the carbon composite cables began in January 1992. This was done on a custom-built fatigue tester, shown in Fig. 18. It consists of a custom-built steel frame, variable speed electric motor, gear reducer, fiberglass tank and custom built crank shaft. The unique loading on the crankshaft combined with the use of closed bearings presented a problem in the design of the crankshaft. The crankshaft had to be made

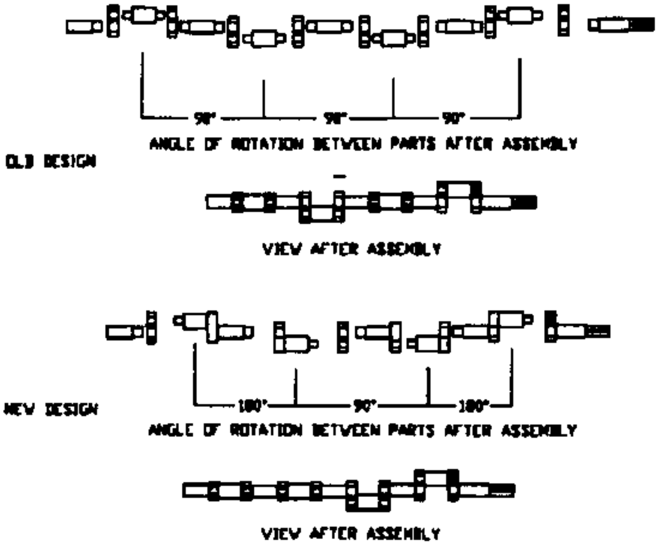

Fig. 19: Fatigue tester crank shaft assembly.

in pieces and assembled around the bearings. The original design consisted of 8 blocks and 9 shafts connected with keys. It employed a 90° offset between each of the four samples. The build up of offset from the allowed tolerance for each of the many key ways resulted in enough unbalance to cause binding points that prevented smooth operation. The repeated reversal of loading on the keys was also a concern. The final solution was to weld together critical crankshaft pieces and change the offset between samples to 180°. This left each of the counterbalanced loads dependent on the tolerance of only one key way. The key way problem associated with the alternating load was overcome by replacing the stock keys with hardened split keys. For added strength the crankshaft was assembled with loc-tite. Fig. 19 shows individual welded assemblies before and after final assembly of the crankshaft.

The tester, which loads samples with a constant and cyclic load while in a sea water bath, accommodates four specimens. The bath is recirculated approximately every 20 minutes. Loading of the samples occurred at three loading levels. Actual load values were obtained by placing a load cell in one of the tether slots and recording the output on an IBM XT computer running LabTech Notebook. Fig. 20 shows a sample of load output for each loading level. Thirty seconds to a minute of these data at each level was then run through a C program that computed overall mean load and mean peak load at both upper and lower cycle limits. Output from this program is shown in Table 1.

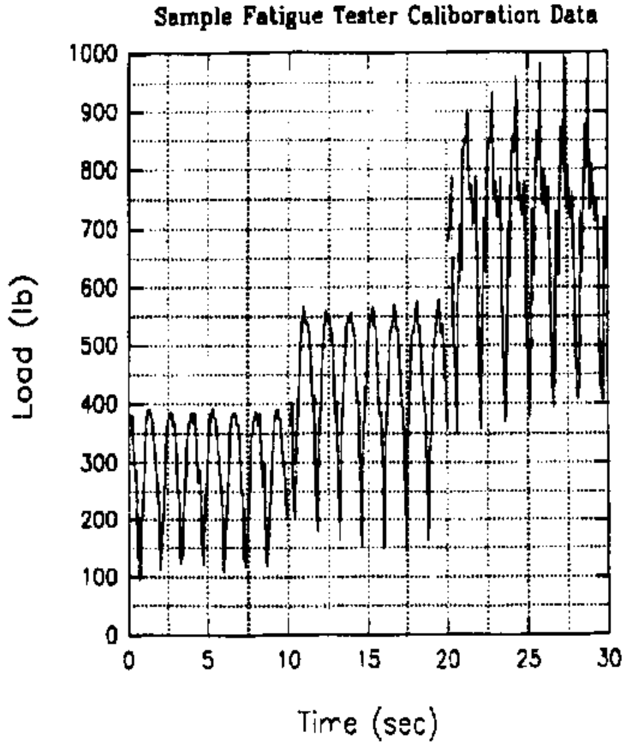

Fig. 20: Calibration data for fatigue tester at 3 loading levels.

Mean Load (lb)	Mean Max Load (lb) %Mean	Mean Min. Load (lb) %Mean
700	830 (+130) 18.6%	550 (-150) 21.4%
450	570 (+120) 26.7%	180 (-290) 40.0%
290	370 (+80) 27.6%	150 (-140) 48.3%

TABLE 1: Calibration data for fatigue tester.

Swivels:

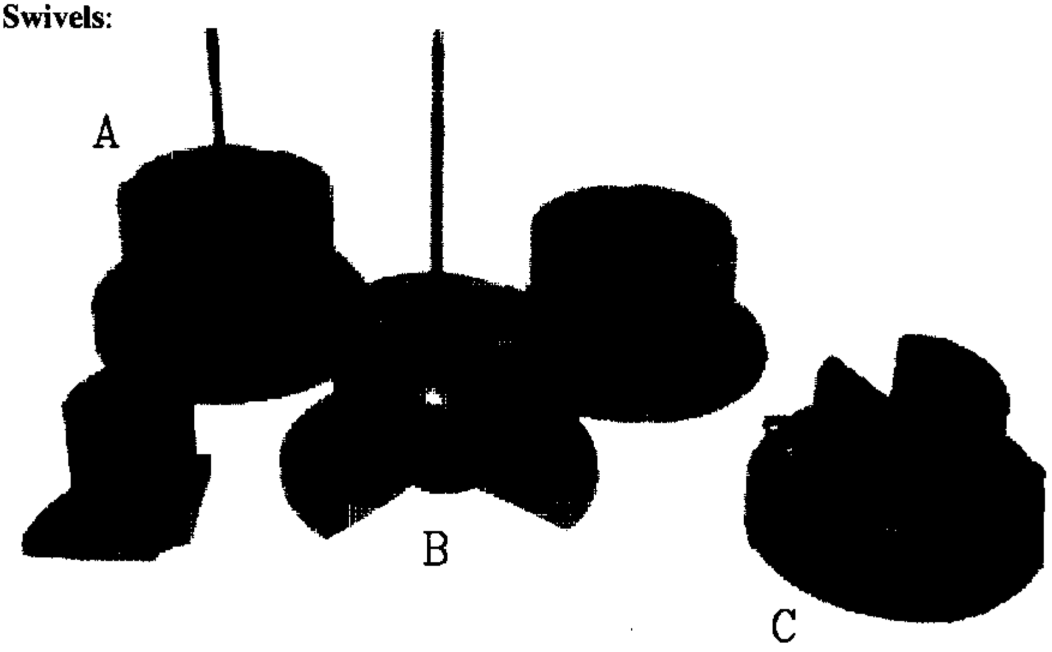

Fig. 21: Swivels (A: ball and socket design together, B: ball and socket disassembled, C: shackle swivel clevis).

The third goal of this project, the development of fatigue-resistant swivels, was completed along with the fatigue testing. Two competing designs - both using non-metallic materials for rubbing parts - were designed and built.

The first of these is a ball and socket joint with a unique split housing and retaining ring which could be installed by a diver. It was centered around a phenolic ball with a threaded insert that attached to the cable termination. The ball was surrounded by a cylindrical housing consisting of four quadrants held together by a sleeve. Each of the quadrants consisted of an Ertalon (a self-lubricating nylon compound) bearing surface held in a PVC support. They were held in place by a PVC sleeve and securely fastened with four bolts. The actual ball swivels are shown in Fig 21a and 21b.

The second has two orthogonal shafts that simulate a double shackle swivel. This design was modeled using a single shackle in the fatigue tester. The model consisted of a

PVC base clevis and threaded steel eye. The hole of the eye was lined a HDPE bearing which was held into the clevis by a single stainless steel bolt. The prototype clevis is shown in Fig. 21c, while the prototype eye can be seen in the next section, Fig. 23.

Initially half of the test tethers were fitted with one design and half with the other of these designs so that fatigue testing of each swivel design was achieved simultaneously. Early in the testing process, however the ball and socket joint was abandoned in favor of the shackle design. This was due to the marked difference in preference between the two. It was surmised that the larger surface area of the ball and socket design provided more friction to motion resulting in early cable destruction.

A problem that later surfaced in the single shackle design was that some of the HDPE bearings began to wear through on one side indicating that the loading on the bearing was not evenly distributed. This problem is expected to disappear on the double shackle design as it will accommodate an additional degree of freedom.

Fatigue Testing:

Actual fatigue testing occurred between January 1992 and August 1992. After they were removed from the fatigue tester tethers were labeled for later examination. The prefix FS designates fatigue sample. The number following this prefix designates each individual tether. (NOTE: All samples mentioned from this point on were tested with the single shackle swivel.)

Four tethers tested at case 1 loading broke at values between 75K cycles and 217K cycles. Five tethers tested at case 2 loading broke at values between 361K cycles and 1.1×10^6 cycles. Of the 5 tethers tested at the lowest level, 1 broke at 840K cycles. The second broke after 5.47×10^6 cycles. The other three withstood 6.31×10^6 cycles without failure. Table 2 summarizes the test results and Fig. 22 shows a S/N curve for the results.

FS #	Dates in Tester	Total Time (wks)	Mean Load (lb)	Cycles (x10^6)
1	1/02/92 - 1/17/92	2.3	700	0.075
2	1/02/91 - 1/17/92	2.3	700	0.075
3	1/08/92 - 1/19/92	1.6	700	0.109
4	1/17/92 - 1/19/92	0.3	700	0.044
5	1/15/92 - 1/27/92	1.7	700	0.217
6	1/17/92 - 2/21/92	5.0	450	0.286
7	1/24/92 - 2/21/92	4.0	450	0.242
8	1/27/92 - 2/24/92	4.0	450	0.326
9	1/24/92 - 1/27/92	0.4	700	0.107+
	2/21/92 - 3/01/92	1.3	450	0.422
10	1/24/92 - 1/27/92	0.4	700	0.107+
	2/21/92 - 3/03/92	1.6	450	0.462
11	2/26/92 - 3/08/92	1.6	450	0.496
12	3/03/92 - 3/20/92	2.4	450	0.225
13	2/14/92 - 3/23/92	1.3	450	1.058
14	4/22/92 - 5/06/92	2.0	290	0.840
15	5/06/92 - 8/12/92	13.1	290	5.472
16	4/22/92 - 8/12/92	16.0	290	6.313+
17	4/22/92 - 8/12/92	16.0	290	6.313+
18	4/22/92 - 8/12/92	16.0	290	6.313+

Table 2: Fatigue Sample Log

Fatigue failure of samples under heavy loading was much like that of the tensile test samples. Fractures in each case were sudden and catastrophic. Broken pieces of the failed tethers flew away at the instant of failure. Most of these pieces were still clearly composite, composed of both J-2 thermoplastic and carbon fiber. In each case the failure appears to be of a mechanical nature.

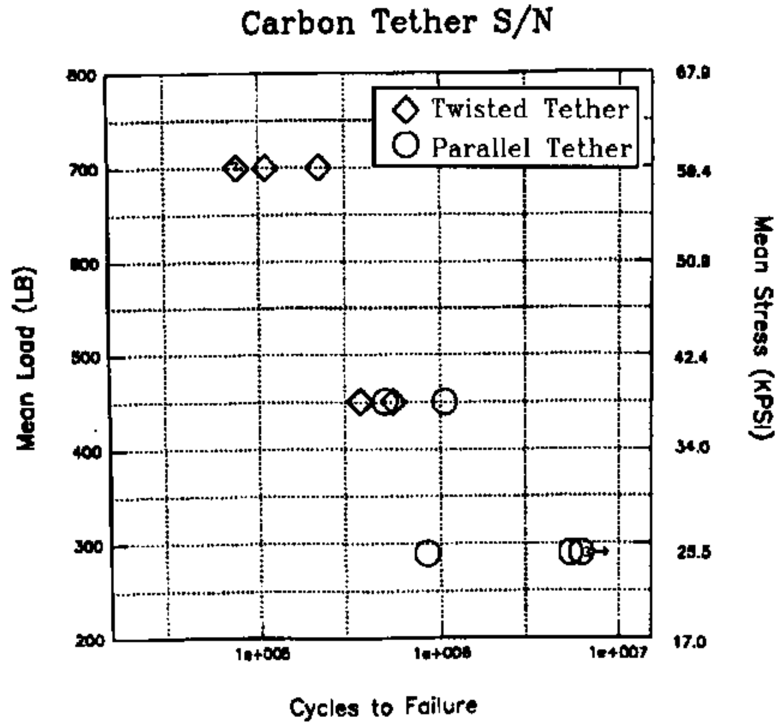

Fig. 22: Carbon S/N Data (A number inside a symbol indicates multiple samples and an arrow to the right indicates unbroken samples.).

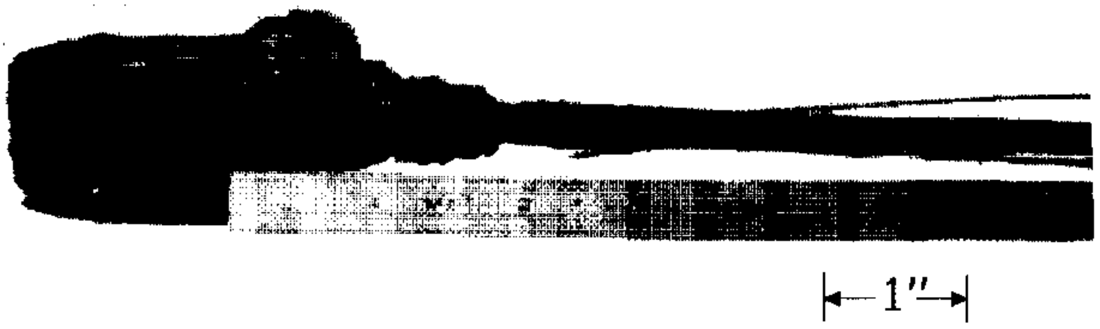

Fig. 23: The base of FS17 shows signs of composite breakdown.

A different type of failure emerged with tethers at the lower load end of the fatigue loading scale. These samples, taking longer to fail, spent a significant time in the seawater bath, and show signs of significant composite breakdown. Individual carbon fibers can be seen separated from the composite matrix. Below the water line, the J-2 thermoplastic is disappearing, leaving only raw carbon fibers to support the load, while the composite structure above the water line appears to be intact. This mechanism of failure, which was first identified in this project (Sloan 1991, Sloan et al, 1991). Sloan found that galvanic cells set up between the graphite and surrounding metal caused chemical reactions which degraded epoxy resins. It was assumed not to have been a problem in these tests because the resin did not contain the radicals that were attacked in Sloan's prior investigations and because the major metal masses were isolated from the graphite by plastic insulators in the swivel attachments. Apparently, the small mass of metal in the termination is sufficient to cause the destructive reaction, and it will occur in the J-2 thermoplastic as well as in the epoxy thermoset resin. The obvious first answer is to incorporate electrical isolation within the termination itself.

Additional Research:

In an effort to further explore the possibilities of this material, single rods of carbon composite were made from the 0.05" wire manufactured for this project. Five wires were pulled through a brass die made from 5/32" tubing (I.D. 0.130") which produce a rod with nearly five times the cross-sectional area of the smaller wires. The largest die used was made from 11/32" brass tubing (I.D. 0.321"). This was the largest possible die for the existing oven. It produced a sample made from 35 of the smallest wires and produced a cross sectional area nearly 35 times that of the original sample.

This was accomplished by laying the pultrusion frame on its side with the line guide and pultrusion oven mounted as shown in the pultrusion configuration (Fig. 1), but without the tow rack. The desired die was placed in the pultrusion oven and enough 0.05" wires to loosely fill the die were slid into place, with enough overhang to be pulled by several half-hitches on the bottom end. A set of two cords attached to opposite sides of the puller wheel with tape were then used in an alternating fashion to pull the wires through the die in much the same way that the original strands were, but taking care not to bend the new larger wire around the wheel.

An attempt was made to produce a sample of the largest size with several optic fibers imbedded for further study of material properties in flex. Very few of the optic fibers survived the pultrusion process, however and a more suitable process has not yet been devised.

The E. I. Du Pont Company provided assistance by providing graphite/thermoplastic materials to be made into wires in our manufacturing process. Du Pont has also provided consulting engineering services on manufacturing technology. Forest E. Sloan, who was a Sea Grant Trainee on this project, successfully defended his Ph.D. dissertation in May of 1991. Dr. Sloan is presently working in industry on the application of high-strength composites and non-metallics to marine applications.

This work is a result of research sponsored in part by NOAA, National Sea Grant College Program, Department of Commerce, under grant number NA89AA-D-SG138, project number R/OE-14, through the California Sea Grant College, and in part by the California State Resources Agency. The U.S. Government is authorized to reproduce and distribute for governmental purposes.

Related Publications

Sloan F. E. and R. J. Seymour 1990. Environmental testing using a compliant load-frame, Journal of Composite Materials, Vol. 24, July 1990, p. 727-738.

Sloan, F.E. 1991. The effects of long-term seawater exposure on grahite/epoxy composite materials. Doctoral Dissertation, Univ. of California San Diego. 231 p.

Lectures

Seymour, R.J. Invited lecture at the Symposium on Composite Materials in Load-Bearing Marine Structures sponsored by the National Research Council, Arlington, VA, September, 1990

Seymour, R.J. Invited lecture at the NSF-sponsored Offshore Technology Research Center at Texas A&M Univ, College Station, TX in December, 1990.
Sloan, F.E. SIO Marine Technology lecture series, January, 1991.

Appendix I: C-Program for Fatigue Tester Calibration

```
/* Program to read load file and compute mean loads */
/* Programer Samuel Massey for carbon tether fatigue project */
/* Ocean Engineering Research Group, Scripps Institution of Oceanography */
/* Voltages from data files were obtained using operational amp B */
/* in the hydro lab fed into an IBM XT computer via an A to D converter */
/* then captured to disk using labtech notebook */

#include <conio.h>
#include <stdio.h>
#include <stdlib.h>
#include <dos.h>

void readfile(void);    /* reads data file for voltages */
void chld(void);        /* converts voltages into loads */
void mnld(void);        /* finds the mean load */
void fracld(void);      /* subtracts the mean load from lds */
void pkvl(void);        /* stores +/- peaks from the mean */
void mnpv(void);        /* computes the mean peak and valley values */

FILE *ldin,*ldout;
float lds[501],meanld,meanp,meanv;
                        /* lds holds load values */
                        /* mnld is assigned the mean load */
float pk[101],vy[101];/* holds the peaks and valleys above */
                        /* and below the mean load */
int p,v;
/* char str[20];*/

void main(void)
{
  readfile();
  chld();
  mnld();
  fracld();
  pkvl();
  mnpv();
  fcloseall();
}

void readfile(void)
{
        float t;
        int n;

        ldin = fopen("c:LOADIN.DAT","r");
        fscanf(ldin,"\n\n\n\n\n\n\n");   /* scan past labtech info */
         for (n=0;n<500;n=n+1)
        {
          fscanf(ldin,"%f %f\n",&t,&lds[n]); /* scan time and voltage */
```

```
          }
}

void chld(void)  /* change voltage to load */
{
   int n;

   for(n=0;n<500;n=n+1)
          {
             lds[n] = lds[n] * 195.2954;
             lds[n] = lds[n] + 11.2307;
          }
}

void mnld(void)   /*find mean load*/
{
   int n;
   meanld = 0.0;
   for (n=0;n<500;n=n+1)
          {
          meanld = meanld + lds[n];
          }
   meanld = meanld / 500;
   printf("\nThe mean load is: %f\n",meanld);
}

void fracld(void)    /* remove mean load to find variable portion of load */
{
   int n;
   for (n=0;n<500;n=n+1)
          {
             lds[n] = lds[n] - meanld;
          }
}

void pkvl(void)  /* find and save peaks and valleys in variable load*/
{
   int n;
   float prev;

   n=0;
   p=0;
   v=0;
   vy[0]=0.0;

   prev=lds[n];
   while (n<500)
          {
                   if (lds[n]<0.0 && lds[n]>prev && vy[v]>prev)
                        {
                             vy[v]=prev;
                        }

                   else if (lds[n]>0.0 && lds[n]<prev && pk[p]<prev)
```

```
                {
                    pk[p]=prev;
                }

             else if(lds[n]<0.0 && prev>0.0)
                {
                    p=p+1;
                    pk[p]=0.0;
                }
             else if(lds[n]>0.0 && prev<0.0)
         {
             v=v+1;
             vy[v]=0.0;
         }


      prev=lds[n];
      n=n+1;
      }

}

void mnpv(void)  /* compute mean for peaks and valleys in variable load */
{
  int n;
  meanp = 0.0;
  meanv = 0.0;
  for (n=0;n<p;n=n+1)
      {
      meanp = meanp + pk[n];
      }
  meanp = meanp / p;
  printf("\nThe mean peak is: %f\n  %f from mean load\n",meanp+meanld,meanp);
  for (n=0;n<v;n=n+1)
      {
        meanv = meanv + vy[n];
      }
  meanv = meanv / v;
  printf("\nThe mean valley is: %f\n     %f from mean load\n",meanld+meanv,meanv);

}
```