

A10360 ULF Cable Summary of Fiber Break Investigation June 29, 1992

Description

The ULF cable segment with broken fibers was returned to Vector Cable at the completion of its service for a failure analysis. The central 0.052" stainless steel tube supplied by Laser Armor Tech consisted of four fibers color coded blue, green, natural¹, and orange. The orange and natural fibers did not have optical continuity. George Wilkins of the University of Hawaii, Tom Coughlin, and Erik Slotboom participated in the final stages of the investigation.

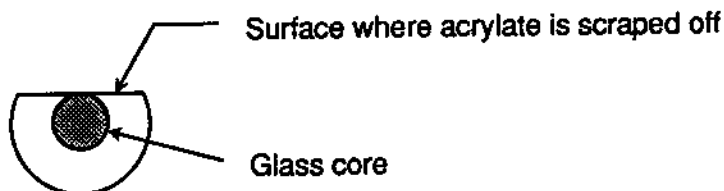
Isolation of the Fiber Breaks

A section of cable was isolated which contained the fiber breaks. The armor and conductor were removed from this segment, and examination of the stainless steel tube revealed a weld where two lengths of stainless steel strip had been joined at Laser Armor Tech. There was discoloration of the stainless steel in the weld zone, but there was no surface irregularity, no roughness, and no mechanical defects on the outer surface of the tube.

Segments of stainless steel tube were removed from the length which contained the break. The metal tube was scored with a file and then broken with gentle flexing so that the fibers would be disturbed as little as possible.

When tube segment 1 (4.95") was removed, the orange and natural fibers moved with the tube as it was pulled away. The fiber breaks were found to be very close to the point where the tube was broken for removal (see diagram). A metal wire was pushed through this 4.95" section of tube to determine if any pieces of fiber remained in the tube. No fiber pieces were found.

Investigation of the broken ends of the fibers showed that the acrylate buffer had been stripped from the glass core on one side of the fiber. An approximate cross-sectional view of the fiber is shown below. The buffer was stripped for about 0.25" on the natural fiber and 0.13" on the orange fiber. Microphotographs of the fiber ends were taken.



The removal of tube segment 2 (4.0") revealed the ends of the two broken fibers (see diagram). The long spacing between the ends of the broken fibers indicated that the fiber break did not occur when the tube was cut. There were no specific events during handling which could have caused this separation, but it cannot be absolutely ruled out that handling caused the separation.

These fiber ends also had stripped buffers. On the orange fiber, the acrylate was stripped around the entire circumference for about 0.1" at the end. An additional approximate 0.025" length displayed stripped acrylate on one side only, similar to the figure above. The cladding on the natural fiber was stripped on one side only for about 0.15". There was no visible damage to the acrylate buffers of the blue and green fibers. Microphotographs of the fiber ends were taken.

The optical continuity was then verified through tube segment 3, which included the weld. The four fibers were then pulled out of tube segment 3 in the direction towards tube segments 1 and 2. The fibers were examined for damage to the acrylate buffer in the region of the weld, but no damage was visible. Black contamination particles were visible along this length of fiber. A few particles (<5) were visible on the side of

¹ This fiber was originally red, but the color had faded to a natural-yellow color. This fiber will be designated as natural.

the weld towards tube segments 1 and 2, and more numerous particles (>10) were visible on the opposite side. This possibly suggests some migration of weld contamination towards segments 1 and 2 if the fiber shifted (possibly during handling), and more numerous particles were picked up when the fibers were pulled out of the tube.

Examination of Stainless Steel Tube

With the fibers removed from segment 3 of the fiber optic tube, the tube was cut into three segments: the central segment including the weld and two short sections on each side of the weld. These segments were individually flushed with trichloroethane, and the solvent/solute solution was collected. When the liquid had evaporated, several small black particles were observed in each of the three samples. A preliminary conclusion was that these particles might be scale (metal oxide) left over from the welding process. As noted below, Herb Karlinski of Laser Armor Tech disagreed with this conclusion.

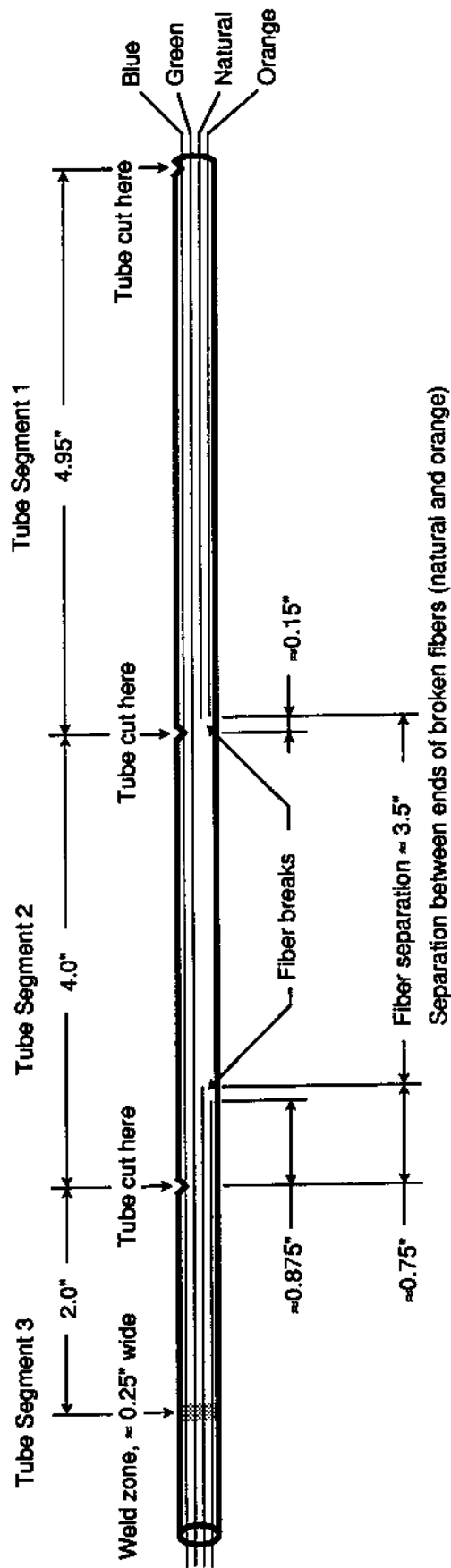
Before dissecting the tube section containing the weld (about 1.5"), Herb Karlinski of Laser Armor Tech (inventor of the metal tube process and president of the company) was contacted to discuss the preliminary findings. Herb made the following comments.

- 1) He believes there is no chance that the tape weld could have contained more than microscopic flaws, and no chance that it could have contained enough oxidation scale to have created a wedge or cutting surface. When the weld is formed, tape thickness and width are swaged to extremely tight tolerances by pressing the weld zone inside a mold. At the same time, both sides of the weld zone are inspected and burnished to a smooth texture. The worst degradation that has ever been observed is a discoloration of the weld zone to a darker texture.
- 2) Herb Karlinski has verified that at the time these tubes were formed and welded, Laser Armor Tech used a guide pin inside the closing die to force the tube seam to remain at the top of the tube (properly aligned for the welding laser). A minor perturbation as the tape weld moved through the die *could* have caused this pin to grab one or more fibers and tear their protective buffers. Exposure of the fiber surfaces could have initiated a process of degradation leading to breakage at a later time under lower stresses.
- 3) Herb has volunteered to analyze this particular matter. The solute samples and the section of tube in the break zone will be delivered overnight. He will examine them and, if appropriate, have the particulate matter identified.

After the telephone discussion with Laser Armor Tech, a miniature grinding wheel was used to open the tape weld tubular section, cutting the side *away* from the longitudinal seam. Looking inside, there was no evidence of any artifact that could have harmed the fiber. The following was observed.

- 1) The same gray discoloration that marked the outside surface of the tube was visible on the inside surface. Apparently, this is a byproduct of the welding process, and it exists on both sides of the tube wall.
- 2) Two circumferential scratches (microgrooves) which probably marked the filleted (filled in) region of the tape weld. These grooves are extremely shallow.
- 3) On one side of these grooves (only), a series of hummocks and pools of welding material which appeared to extend for not more than two tube diameters along the tube. These contours had extremely low profile - probably much less than a mil (i.e., less than 25% of the tube wall thickness). Such contours are consistent with a model in which the bead of liquid metal was disturbed as the tape weld passed through and interacted with the closing die.

Microphotographs were taken of the outside and inside surfaces of the tube in the weld zone.



Note: The blue and green fibers were continuous over the three tube segments.

Diagram of Tube Cuts and Fiber Positions

Conclusions

No unique or definite reason can be isolated for the breakage of the orange and natural(red) fibers in this section of the ULF cable. At the same time, it stretches the laws of coincidence beyond reason to assume coincidence for the occurrence of two fiber breaks within 8 cm of the welded section. Tape welds occur every 2000 meters. The ratio of these two distances is 1/25,000. For two fibers to break at the same point has a random probability roughly equal to the square of this ratio.

No internal artifact that could have caused these breaks was identified, and the investigators believe that such structures were not the cause. This point will be checked again after analysis of the black detritus is completed.

At the moment, the alignment pin described by Herb Karlinski is the most likely cause of the double fiber break. This pin could have shaved off acrylate buffer which subsequently was burned by the welding laser, possibly accounting for the black particulate matter. The pending analysis of the particulate matter will provide more insight into this possibility. This pin is no longer used in manufacturing.

At no time during the post mortem investigation was any evidence of fiber jamming and/or microbending observed. The fibers lay straight in the tube with little or no evidence of helix cycling.

University of Hawaii at Manoa

Hawaii Institute of Geophysics
School of Ocean and Earth Science and Technology

MEMORANDUM

AUGUST 20, 1992

From: George Wilkins, HIG, Room 320 *GW*
To: DUMAND, Shore Cable

Subj: Results Of Post Mortem of ULF E-O Tube

1. In June, Eric Slotboom of Vector and I wrote a memorandum which discussed and explained the causes and modes of failure of two optical fibers within an 8-km length of the 4-fiber E-O tube that forms the heart of the ULF cable. These fibers broke at the same place (plus/minus 5 cm). According to the manufacturer (Laser Armor Tech), the most likely cause was cutting of the fiber buffers by a knife blade which had been used to align the tube seam in preparation for laser welding. This alignment technique is no longer used, and was not used for the DUMAND electro-optical tubes.

At my request, Vector sent the broken fiber ends plus that length of tube which contained the fiber failures to the manufacturer (Laser Armor Tech) for analysis and comment. The results of the LAT investigation are presented below.

- (1) The ashy black residue found within the tube at the failure point is "almost certainly" fiber buffer shavings which have been altered (carbonized?) by relatively high temperatures. This is deduction only, since not enough ash was found to support chemical analysis.
- (2) LAT now fully believes its initial conclusion that the buffer residue was created by a cutting action of the knife point used to align the tube seam in preparation for laser welding.
- (3) Penetration of the knife point into the tubular cavity was probably caused by a perturbation or "bump" of the tape as it passed through the closing die. This conclusion is reinforced by:
 - (a) Verification that the fiber failures occurred almost exactly (within 5 cm) of the point where two sections of tape had earlier been butt welded. (Butt welding is a normal procedure, since tapes can be purchased only in lengths of 2 km or less.)

- (b) Discovery of a die mark on the outside of the tube at this weldment point. This die mark is automatically applied whenever an inline eddy current monitor detects a zone where the weldment seam is not hermetically sealed. Such flaws are extremely rare occurrences and, when they do occur, almost invariably take place at a tape weld. They are probably caused by a perturbation of the tape as the butt-welded joint is pulled through the die. (It should be noted, however, that these joints are highly polished on both sides immediately after welding.)
- (c) Observation of rounded "bumps" of weldment material clustered about the tape weld on the inside of the tube. These are caused by a pulsed laser which is used to regain tube hermeticity. The optical fibers and shavings are fully exposed to these welding pulses---i.e., they have no protective barrier as they did during fiber insertion into the tube. It is therefore probable that the shavings were altered by excess heat. Direct damage to the fiber buffers is much less likely, since the tube is convex to the welder, and the fibers would occupy the bottom of the tube with a void-filling material acting as insulation between them and the upper wall of the tube.

Two factors----the knife tip alignment device and crowding of the optical fibers into an overly small tube---were identified by LAT as the primary culprits leading to the failures of the ULF fibers. The knife alignment technique had already been abandoned when the DUMAND E-O tubes were fabricated. Also, the 12 DUMAND occupy a much smaller fraction of the pre-drawdown internal area of the stainless steel tube. LAT feels that such weaknesses and associated failures are extremely unlikely for the DUMAND cables.


GEORGE WILKINS