Test Report AV-0394
Evaluation of Fibre Optic Mechanical Splice (AVLiteSplice)
Revision: 1 - Preliminary Product Test Data

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Prepared by: Dr G.M.Proudley, PhD MIET

AVoptics Ltd
3, Limber Road, Lufton Trading Estate
Yeovil, Somerset, BA22 8RR, UK

DOCUMENT REVISION TABLE

Revision	Date:	Description of Changes:	Name:	Checked:
A	17/11/20	Draft Release	G.M.Proudley	
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2				

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1. Introduction

AVLiteSplice is a repair solution for fibre optic cables. It is designed to reinstate damaged or compromised cables on a harsh environment platform (e.g. aerospace, marine, rail or land vehicles). By providing a robust repair solution and providing repaired performance in line with the original cable, such a splice can obviate the need for cable or full harness replacements (which can incur substantial material, time and labour costs).

To evaluate the splice, development tests have been performed to prove elements of the splice and to aggressively test the final assembly. This document provides a summary of results from the following tests:

- HALT (Highly Accelerated Lifetime Tests)
- Temperature Cycling of 2nd design iteration
- A400M Vibration Test (from MIL-STD-810F Method 514, Category 13) of 2nd design iteration.
- Tensile Pull tests on the internal splice terminations with Field Cure Oven (AVliteCure(TM))

It is noted that these tests were performed as part of product development. They represent preliminary product data and provide confidence in the splice performance. Although not part of formal standard testing it is noted that HALT testing provides a more comprehensive product test than many isolated single parameter tests. The combination and variation of parameters such as temperature and vibration is designed to induce product failures and weakness in design. It is therefore of great value in assessing product performance.

The tests presented here focus mainly on multi-mode fibre cables. The splice is equally applicable to single-mode repair and a limited amount of single-mode test data is also presented.

1.1 A Note on Cable Performance:

It is noted that the fibre optic splice is designed to reinstate a damaged or compromised cable. Testing therefore requires the use of real fibre optic cable samples. Tests were predominantly performed on representative samples of a high-performance fibre optic aerospace cable.

Cables were manufactured by Carlisle (Tensolite) with product codes:
Multimode - Carlisle P/N: NFO-TS-135-3M3
Singlemode – Carlisle NFO-(TS)-150-5B

These cables have a baseline temperature rating: -65C to 135 °C but have been tested at higher temperatures up to 175 °C (for thousands of hours). Other cables may have more limited temperature operation.

A small number of cables from an alternative manufacturer were tested in Vibration. These were Multimode cables manufactured by Gore (code GSC-13-83259-00).

2. Test Requirements

The main function of a fibre optic splice, once assembled, is to maintain the alignment of two optical fibres to a high degree of accuracy (~1 µm) over extreme environmental conditions (e.g. extreme vibration and temperature). Clearly vibration could cause changes in alignment as could expansion and contraction of the parts with temperature.

Insertion loss is the additional optical loss introduced into a cable by performing the splice. Suitable tests therefore monitor the insertion loss of the fibre optic splice over extremes of environment. Absolute Insertion Loss and changes in Insertion Loss are measured in dB.

The performance spec for the splice was set as follows:

Multimode Insertion loss: 0.5dB MAX

Operating temperature range: -65°C to 150 °C.

Residual attenuation: not to exceed 0.25 dB in any test

Note: These values are similar to common airframe fibre optic connector loss limits. Loss, or attenuation is a key parameter in any fibre optic link. A fibre optic system will have a finite link budget indicating the maximum allowable losses for components such as cables, connectors and splices to maintain link operation.

Details of each test performed, and results are now presented.

3. Tests

3.1 HALT

HALT (Highly Accelerated Lifetime Testing) is a natural choice for testing and proving a design over extremes of temperature and vibration. It is a key tool in product development.

3.1.1 Ref Docs:

Environmental Test Report - ENV6290 ABTest/AVoptics

3.1.2 HALT Test Overview:

HALT comprises a number of tests designed to gradually expose the samples to more and more aggressive environmental stress. Test envelopes are based on the initial design specification.

HALT testing comprises the following sub tests:

1) Temperature stepping (exploratory) – moving between limits and looking for changes in splice performance (-70 to +155 °C)
2) Temperature Cycling between limits at rates of 30, 45 & 60 degrees/min between -60 and +150 °C.
3) Vibration (wideband 10-2000Hz) up to 50g.
4) Combined Temperature/Vibration. -60 to +145 °C at 5, 10, 20, 30 & 50g rms (one cycle each). Ramp rate @ 60 °C/min.

Optical power transmitted through the splice samples (mounted on aerospace grade cables) was continuously monitored throughout each test. Light signals were cw (continuous wave) with no data modulation. This allows loss characteristics to be correlated with environmental conditions.

3.1.3 Sample Preparation & Comments:

Seven samples of multi-mode and one sample of single-mode (aerospace grade) fibre cable were prepared and then cut and repaired with AVLiteSplice.

Control cable samples of each type were also tested (with no additional splice) for comparison.

Cable Type: Length 2m in test chamber. All samples were the same length. Cable types were as follows:

Multimode - Carlisle P/N: NFO-TS-135-3M3
Single-mode – Carlisle NFO-(TS)-150-5B

Splice bond epoxy – EpoTek OD2002 (Cure 150 °C for 60 mins)

Splice Assembly Torque – 0.5 Nm (Splice threads were treated with threadlock – Loctite 243)

The test samples were pre-assembled and secured to the HALT chamber test bed via a rigid test fixture.

3.1.4 HALT Test Equipment

HALT chamber: Thermotron – Halt Hass. Cal 0/748 (In Calibration at time of test)

Accelerometer: Tri-Axial Accel PCB Peizotronics. Cal 0/799 (LW201849)

Light Sources:

Multi-mode 850nm Multi channel LED module. 90% LPS launch (Arden Photonics).
Single-mode 1550nm Tunics laser. Model PR-1550, S/N: 10-3455
(Controller 3642-CR-00/Head 3642-HE1550)

Light Detector – EXFO IQS605P-I3, Modular Test System, S/N 452314
2 x 4 Channel Power Meter Modules IQS-1643W, (S/N 451174 & 451175). Absolute calibration not required (linearity only).

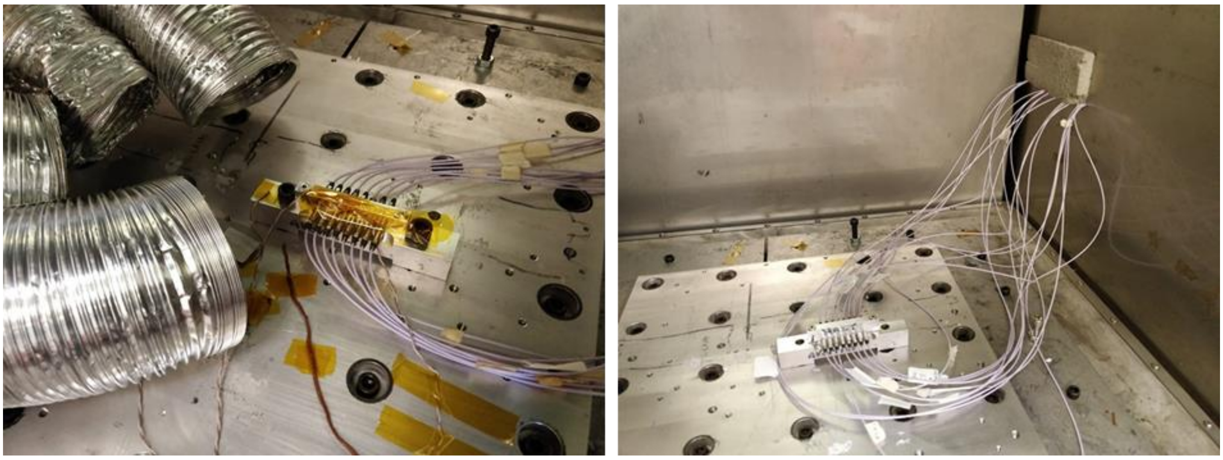


FIGURE 1 HALT TEST SET-UP SHOWING SAMPLES MOUNTED ON VIBRATION BED IN TEST CHAMBER

3.1.5 Test Pass Requirements:

Multimode Insertion loss of 0.5dB MAX

Residual attenuation not to exceed 0.25 dB in any test

3.1.6 HALT Results Summary:

HALT test results are presented in Table 1 and Figure 2.

HALT Test	**Test Limits**	**Maximum Insertion Loss Change (dB)**	**Comment**	**Pass/Fail**
Exploratory temperature steps between limits	-70 to +155 °C	-0.15 dB (multi-mode) -0.08 dB (single-mode)	One cold step excursion followed by one hot excursion. Step increments of 5 °C.	Pass
Rapid Temperature Cycling between limits	-60 and +150 °C.	+0.19/-0.15 dB (multi-mode) -0.045 dB (single-mode)	Rates of change 30 (x5), 45 (x10) & 60 °C (x5) /min Cycle number in parenthesis.	Pass
Vibration (wideband).	10-2000Hz up to 50g rms	0.025 dB (multi-mode). 0.15 dB (single-mode).	Multi-axis vibration. 20 °C sample temp. 15 mins at 10, 20, 30, 40 & 50 g (RMS)	Pass
Combined Temperature/Vibration.	-60 to +145 °C	0.12 dB (multi-mode) 0.07 dB (single-mode)	10, 20, 30 & 40g rms (one cycle each). Ramp rate 60 °C/min. With multi-axis vibration	Pass
Extreme test	~190 °C combined vibration 50 g rms at limit.	-0.17 dB (multi-mode only)	Two multi-mode samples. One rigidly mounted, one loosely mounted.	Pass

TABLE 1 SUMMARY OF SPLICE PERFORMANCE IN HALT TESTING

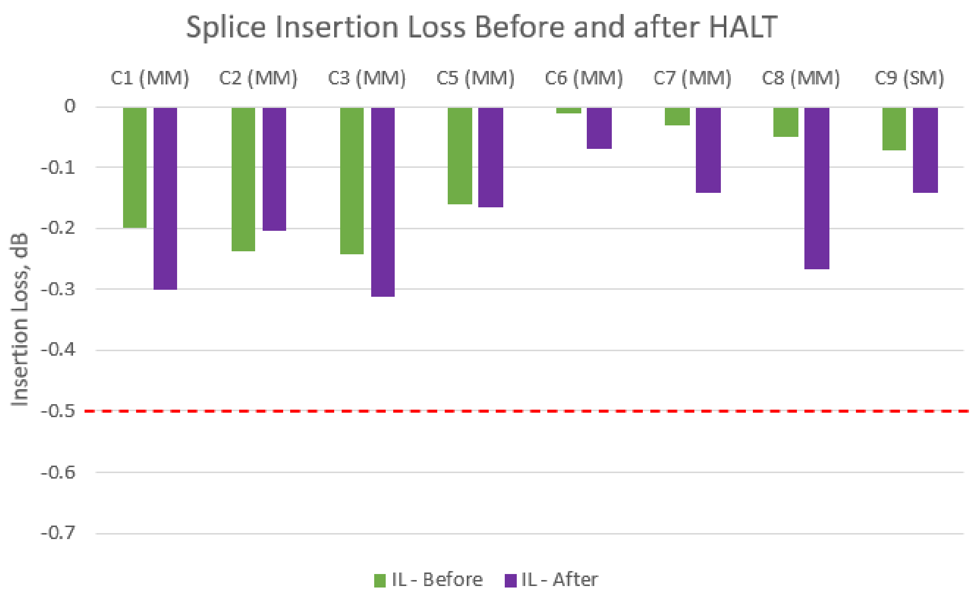


FIGURE 2 INSERTION LOSS DATA BEFORE AND AFTER HALT TESTING. (MM = MULTI-MODE (50/125), SM = SINGLEMODE (9/125). RED LINE INDICATES PERFORMANCE SPECIFICATION LIMIT.

3.1.7 Conclusion:

All test specimens exceeded the selected performance criteria during HALT Testing

3.2 Temperature Test Results (Design Iteration 2):

Further testing was carried out on an improved design for easier field termination. Confidence testing was performed on a limited number of samples over temperature to monitor insertion loss change. Results are presented in Table 2 and Figure 3.

3.2.1 Test OVERVIEW

The cw optical power change through the cable samples was monitored over the temperature test. Results are presented in Table 2 and Figure 3.

3.2.2 Sample Preparation & Comments:

Two samples of multi-mode and one sample of single-mode (aerospace grade) fibre cable were prepared and then cut and repaired with the AVLiteSplice optical splice. Control cable samples of each type were also tested with no additional splice on the cable.

Cable Type: Length 2m in test chamber. All samples were the same length. Cable types were as follows:

Multimode - Carlisle P/N: NFO-TS-135-3M3

Single-mode – Carlisle NFO-(TS)-150-5B

Splice bond epoxy – EpoTek OD2002 (Cure 150 °C for 60 mins)

Splice Assembly Torque – 0.5 Nm (with additional thread-lock – Loctite 243)

3.2.3 Test Equipment

CME PAC-540-B-H - Temperature Humidity Chamber S/N: 120235.

Temperature Sensor: PicoLog TC-08 S/N: ZJY40/444 (in calibration at time of measurement).

Light Sources: Multi-mode 850nm 24-channel LED module. OptoTest OP750-LD-24-85-FP (S/N 14463). Encircled Flux launch condition (IEC61280-4-1). Single-mode 1550nm Tunics laser. Model PR-1550, S/N: 10-3455
(Controller 3642-CR-00/Head 3642-HE1550).

Light Detector Unit: OptoTest InGaAs Power Meter Module (24 Channel) OP710-24-IN1. S/N 14472. In Calibration at time of test.

3.2.4 Test Pass Requirements:

Multimode Insertion loss of 0.5dB MAX

Residual attenuation not to exceed 0.25 dB in any test

3.2.5 Temperature Test Result Summary

Test	**Test Limits**	**Maximum Insertion Loss Change (dB)**	**Comment**	**Pass/Fail**
Temp Cycling	-65 to +150 °C	+0.07/-0.04 dB (multi-mode) -0.13 dB (single-mode)	2 samples multi-mode 1 sample single-mode 7 Temperature Cycles RT to 150 C 5 °C/min RT to -60 °C 3 °C/min	Pass

TABLE 2 TEMPERATURE CYCLING TEST FOR 2ND DESIGN ITERATION.

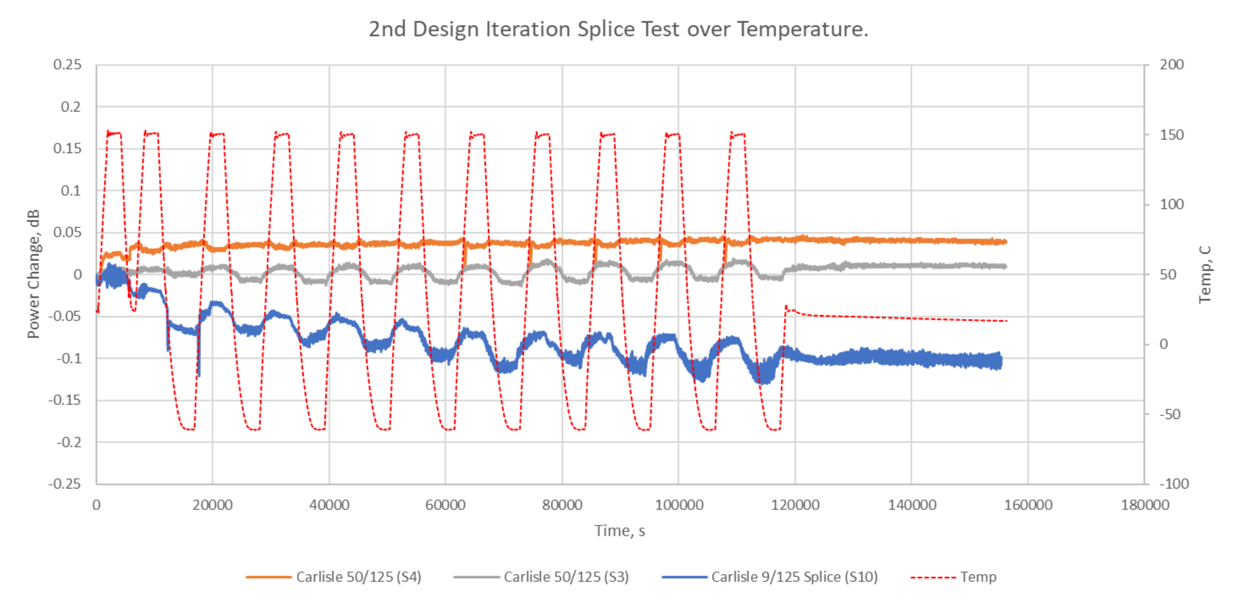


FIGURE 3 TEMPERATURE CYCLING TEST FOR 2ND DESIGN ITERATION SPLICE. EXAMPLE LOSS CHANGE DATA.

3.2.6 Conclusion:

All test specimens exceeded the selected performance criteria during temperature testing.

3.3 Vibration Test (A400M)

Selected samples were tested in a random vibration test applicable to equipment installed on a propeller aircraft as defined in MIL-STD-810F Method 514, Category 13.

3.3.1 Test Overview

The splice was tested over the levels detailed in Table 3 and Figure 4 applied for 4 hours per axis.

Broadband background*	**Narrow band spikes (g^2/Hz)**			
	F_0 : 78Hz - 118Hz	2 **F_0** : 159Hz - 236Hz	3 **F_0** : 239Hz - 354Hz	4 **F_0** : 369Hz - 472Hz
0.02g^2/Hz 5.0 10^{-3} g^2/Hz	1.5 10^{-1}	3.75 10^{-2}	1.65 10^{-2}	9.375 10^{-3}

* For frequencies up to 60Hz, a broadband background vibration level of 0.02 g^2/Hz was maintained.

TABLE 3 DETAILS OF A400M VIBRATION TEST PERFORMED ON AVLITESPLICE SAMPLES.

The samples were tested for four hours along each orthogonal axis (both along and normal to the optic axis of the splice). The cw transmitted optical power was monitored throughout the test. The test set-up is shown in Figure 5.

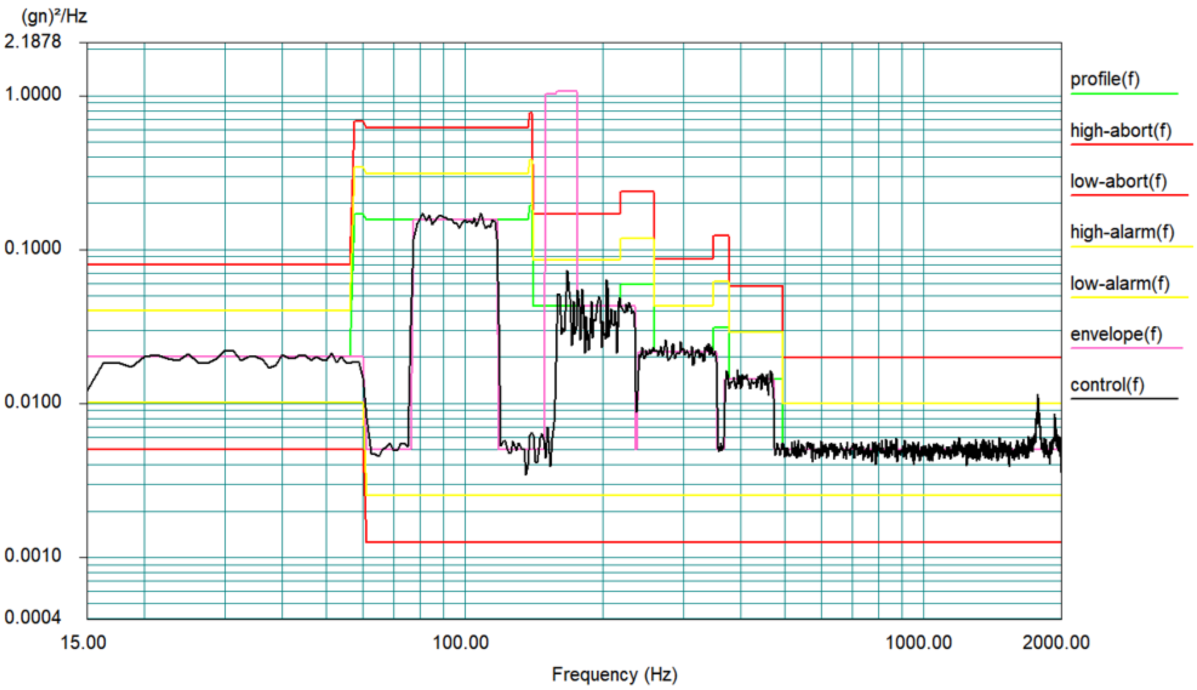


FIGURE 4 VIBRATION SPECTRUM FOR A400M TEST ON AVLITESPLICE.

3.3.2 Sample Preparation & Comments

Several samples of multi-mode and single-mode (aerospace grade) fibre cable were prepared and then cut and repaired with the AVLiteSplice optical splice. They were then mounted on the head of an electro-dynamic shaker system.

The tested samples comprised

3 x Multimode - Carlisle P/N: NFO-TS-135-3M3
2 x Gore - GSC-13-83259-00 (EN4641-301)
1 x Single-mode – Carlisle NFO-(TS)-150-5B

Splice bond epoxy – EpoTek OD2002 (Cure 150 °C for 60 mins)

Splice Assembly Torque – 0.5 Nm (with additional threadlock – Loctite 243)

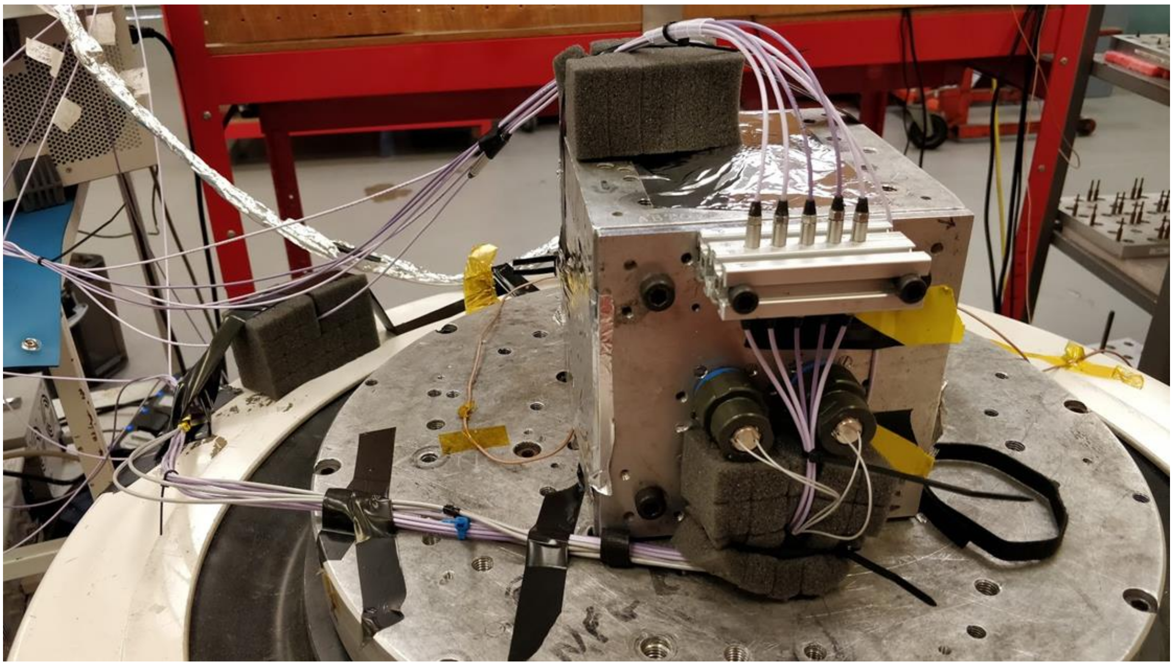


FIGURE 5 A400M VIBRATION TEST SET-UP SHOWING AVLITESPLICE SAMPLES (BEING TESTED ALONG THE OPTIC AXIS).

3.3.3 TEST EQUIPMENT

Vibration System:

LDS Electro-dynamic shaker. Model V850. Calibration 0/768b
Amplifier LDS Calibration 0/768a
Controller LDS-Dactron Calibration 0/681
Accelerometer PCB Calibration 0/017 (SN 8712)
Software Shaker Control LaserUSB 8.10.0193

Optical Monitoring:

Light Sources: Multi-mode 850nm 24-channel LED module. OptoTest OP750-LD-24-85-FP (S/N 14463). Encircled Flux launch condition (IEC61280-4-1).

Single-mode 1550nm Tunics laser. Model PR-1550, S/N: 10-3455
(Controller 3642-CR-00/Head 3642-HE1550)

Light Detector Units: OptoTest InGaAs Power Meter Module (24 Channel) OP710-24-IN1. S/N 14472. In Calibration at time of test.

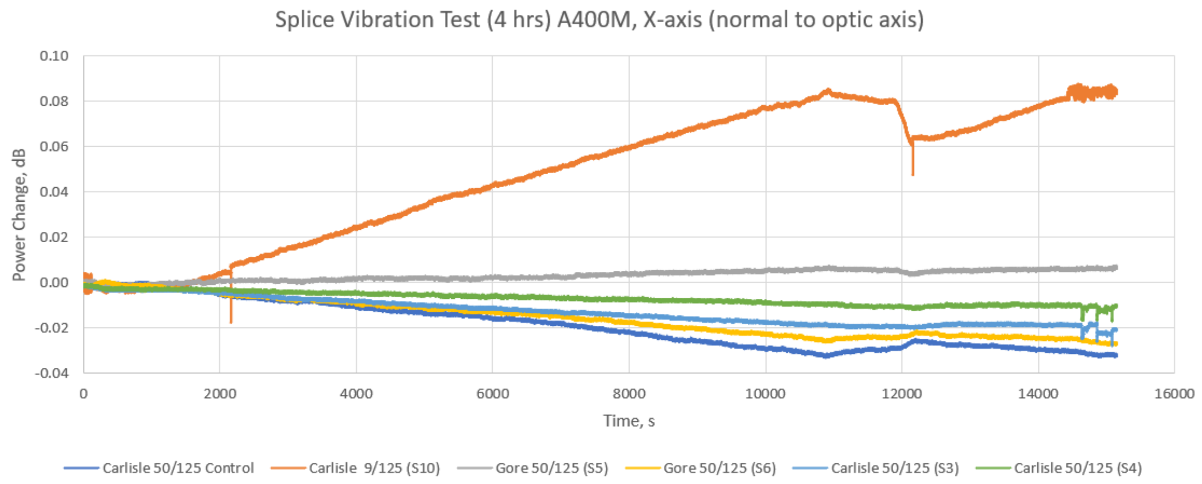
Light Detector – EXFO IQS605P-I3, Modular Test System, S/N 452314
4 Channel Power Meter Modules IQS-1643W, (S/N 451174). Absolute calibration not required (linearity only).

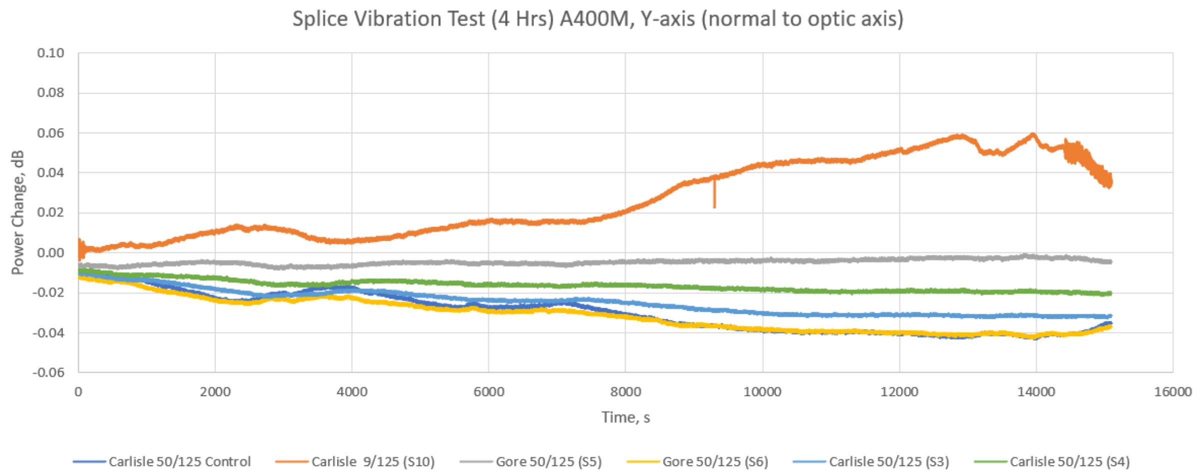
3.3.4 Test Pass Requirements:

Residual attenuation not to exceed 0.25 dB in any test

3.3.5 Vibration Test Result Summary

Splice transmittance tests are presented in the graphs of Figure. 6 and the summary Table 4.





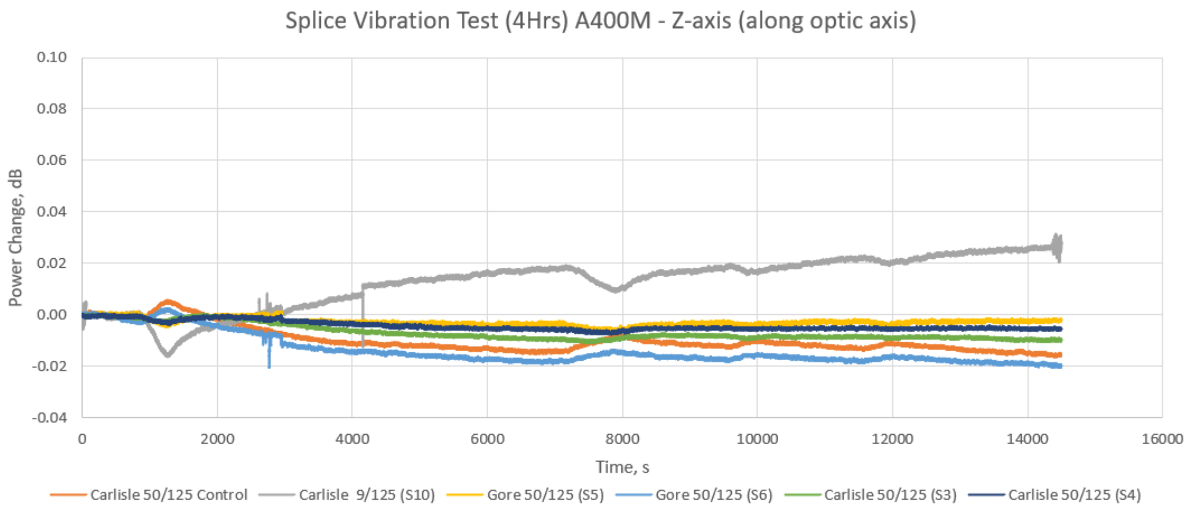


FIGURE 6 AVLITESPLICE TRANSMISSION OVER A400M VIBRATION TEST. 3-AXIS DATA. 4 HOURS PER AXIS.

	Max dB Change (MM 50/125 µm)	Max dB Change (SM 9/125 µm)
X-Axis	+0.006 dB -0.028 dB	+0.088 -0.018
Y-Axis	-0.042	+0.06 -0.003
Z-Axis	+0.007 -0.02	+0.032 -0.016

TABLE 4 SUMMARY OF AVLITESPLICE TRANSMISSION CHANGES OVER A400M VIBRATION TEST

3.3.6 CONCLUSION

All test specimens exceeded the selected performance criteria during temperature testing.

3.4 TENSILE PULL TESTS ON CABLE TERMINI USING FIELD CURE OVEN

Following an extensive test programme on the AVliteSplice terminus (the component that secures the optical fibre and provides precise alignment as well as bonding to the cable), an optimised ferrule design was produced. This terminus has an optimised carrier length, surface finish and cable surface preparation method to produce optimised bond strength. It has been established that the bond strength between the termini and the cable was in excess of 200N using a standard epoxy cure schedule and bench oven. Typically this involves a cure time of at least an hour.

Further tests have been performed to establish the attainable pull force for curing the bonding epoxy with a portable field cure oven (AVLiteCure – AVT-276). This oven is ideal for performing repairs on aircraft and has recently been qualified by Airbus to allow terminations to be performed on aircraft. This device can be included as part of any splice kit to support the repair splice. It can reduce the cure time down to <15 minutes. The AVLiteCure oven is shown in Fig.7.

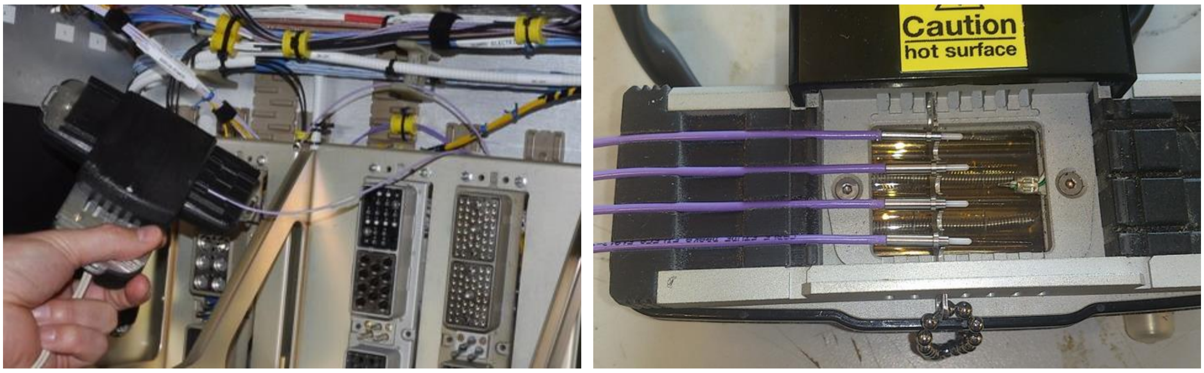


FIGURE 7 THE AVLITECURE OVEN CAN BE USED FOR FIELD TERMINATION OF THE AVLITESPLICE. IT CAN BE USED TO CURE MULTIPLE SPLICE TERMINI AS SHOWN IN THE IMAGE ON THE RIGHT.

3.4.1 Test Overview

The test involved terminating a batch of cable samples with AVLiteSplice termini (ferrule + carrier), curing the samples using the AVLiteCure field repair oven. The resulting strength of the cable to carrier bond was then tested using a tensile test machine at a load rate of 10mm/minute.

3.4.2 Sample Preparation

Ten cable samples were prepared using a 1.8 mm diameter PFA jacketed fibre optic cable manufactured by Draka (F1913-12). This cable jacket is considered to be challenging in achieving a high strength bond. The cable ends were prepared and terminated with an AVLiteSplice ferrule carrier. The bonding Epoxy was EpoTek353ND. Cure time in the AVLiteCure oven was 12 minutes (oven pre-set for ARINC 801 termini). Cable length was 0.5m.

3.4.3 Test Equipment

AVLiteCure Oven

Mechmesin MultiTest 2.5-d tensile test machine (Figure 8)

250N load cell (AFG 250N) (max target strength was 200N). The load rate was 10 mm/minute and the target dwell time at max load was 60 seconds.

Promet Fibo Interferometer (to check any fibre movement in ferrule after test).

FIGURE 8 TENSILE TEST MACHINE USED TO MEASURE BOND STRENGTH OF CABLE TO SPLICE TERMINUS.

3.4.4 Test Pass Requirements:

Bond strength >111N for 60 seconds (Airbus requirement for 1.8 mm diameter jacket cable)
Target ~200 N for 60 seconds.

3.4.5 Test Result

The strength results for samples cured in the AVLiteCure oven are presented in Fig. 9. As can be seen, the strength was high with nearly all samples meeting the 200N, 60 second duration target. Most samples did not break even when nearing the load cell limit of 250N.

3.4.6 Conclusion

All samples met the Airbus test requirement and exhibited bond strength able to withstand >180N. This bond strength was achieved with a portable field cure oven (AVLiteCure). Axis ?

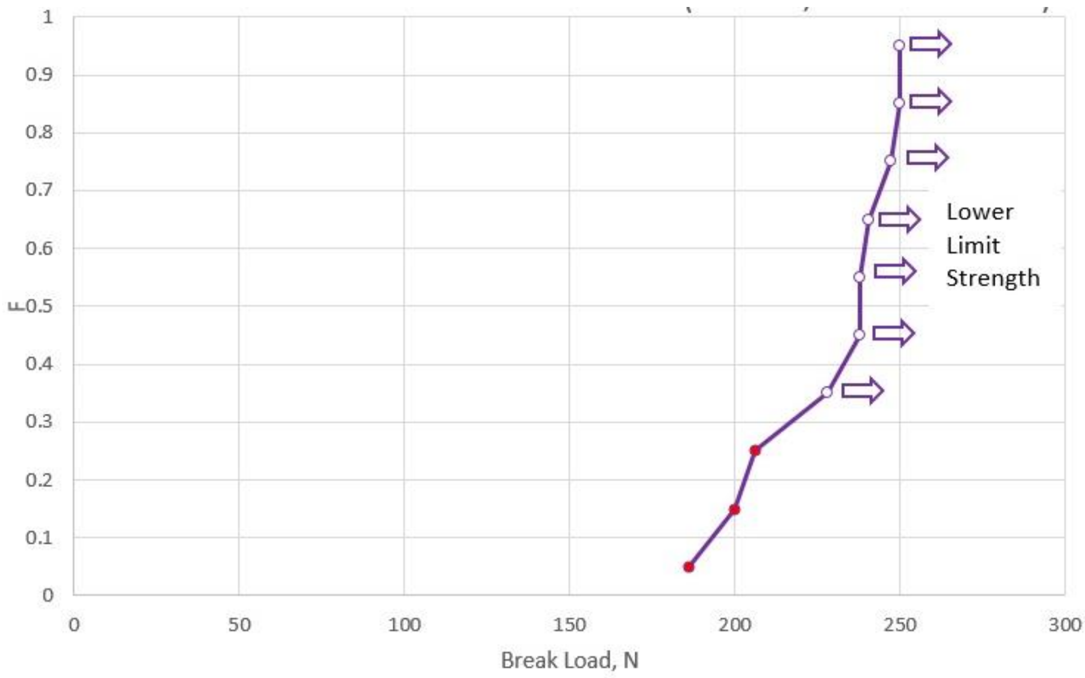


FIGURE 9 PLOT SHOWING STRENGTH OF FERRULE CARRIER/CABLE BOND FOR 1.8 MM PFA JACKETED CABLE CURED IN AVLITECURE FIELD REPAIR OVEN. RED DATA POINTS DENOTE SAMPLE BREAKS. OPEN DATA POINTS SHOW LOWER LIMIT STRENGTH.

4. Conclusion

This report presents preliminary product test data for a new fibre optic repair splice (AVLiteSplice™). The splice is designed to reinstate damaged or compromised cables on a harsh environment platform. Repair time of the splice can be as short as 20 minutes*. The initial design tested is appropriate for 125 µm diameter fibre (both single and multi-mode) in 1.8 mm diameter fibre optic cables. The design is adaptable for APC termini and larger cable sizes.

Development tests have been reported to prove elements of the splice and to aggressively test the final assembly. Tests have included HALT (Highly Accelerated Lifetime Tests), temperature cycling, and A400M vibration testing (MIL-STD-810F Method 514, Category 13). The splice baseline performance specification of 0.5 dB maximum insertion loss, residual attenuation < 0.25 dB and operating temperature range of -65°C to 150 °C (cable dependent) have been met in all tests for both multi-mode and single-mode cables. In addition, the bond retention pull force of the optical terminus has been tested with strength >180N when cured with a portable field cure oven (AVLiteCure™). These tests provide confidence in the performance of the splice over harsh environments. They are also a precursor to formal qualification tests for any specific harsh environment platform.

**Using an approved Field Repair Kit*

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