LIGHTEST AND SMALLEST LOW EARTH ORBIT WIRES AND CABLES TYPE LEW ACCORDING TO ESCC 3901/026

Nicole Kaika[(1)], Erwin Zäh[(1)], Peter Parketta[(1)]

[(1)] ***W. L. Gore & Associates GmbH,***
Nordring 1 91785 Pleinfeld, Germany
Email: nkaika@wlgore.com

ABSTRACT

Increased electrification in satellite technology requires more cable. Lower cable mass and smaller diameter will save installation space and directly impacts mission cost. W. L. Gore & Associates GmbH have qualified ESCC 3901/026 lightweight ATOX resistant cable variants for LEO orbit applications thin high strength fluoropolymer insulation material. Although insulation wall thickness minimized in designs, newest ESCC3901/026 Detail specification will maintain heritage 600 Vrms operating voltage and ±200°C temperature characteristics. This have been qualified according to ESCC 3901 low frequency wire and cable Generic Specifications' requirements and qualification test plan has incorporated beyond limit testing for ESCC 3901 cables for the first time.
Product concept, design characteristics and application benefits in the context of heritage ESCC 3901 cable variants are illustrated and ESCC 3901 qualification incl. beyond limit test approach resulting into ESA Certificate of qualification No 373 is summarized.

INTRODUCTION

Wire and cable designs used for long term space missions require durable and robust insulation materials to ensure mission lifetimes up to 25 years in harsh environment. One of the challenges when operating in LEO orbit is erosion of engineered plastics by atomic oxygen [1]. Polytetrafluoroethylene (PTFE) based material have shown best ATOX persistence when comparing Polymers used in spacecrafts and ended up with lowest erosion rate and mass loss after years flown in LEO [2].
GORE® has developed very thin toughened PTFE tapes enabling to realize wire designs with extremely thin wall size although two independent insulation layers compliant to ESCC 3901 and operating up to 600V, -200°C to +200°C. 21 commonly used cable variants have been qualified according to ESCC 3901 Generic Specification. [3]
ESCC3901/026 cable variants maintain operating characteristics, allow mass savings up to 47% and up to 27 % lower diameter compared to existing ESCC qualified cable products to improve total mission costs and commence new low bend radius design opportunities. [4]

DEVELOMENT OBJECTIVES

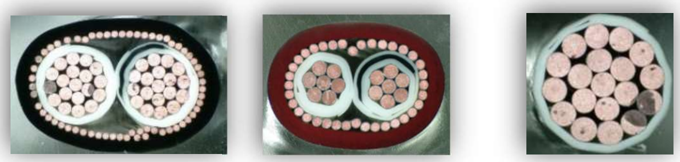
The initial product concept claimed to develop the lightest Space cable designs fully qualified to ESCC 3901 Generic Specification to list it on the ESA Qualified part list. The objective was to achieve weight reductions of 8% to 35% (depending on variant) and less diameter compared to next best ESCC 3901 alternatives using ATOX resistant materials with erosion rate less than 1.73 E- 25 cm^3/atoms only. Goal was to realize a portfolio of frequently used cable constructions with no tradeoffs for operating voltage and temperatures compared to GORE heritage Space qualified products. Mechanical wire parameters like abrasion resistance or cut through resistance must end up in the same range or better when compared to existing ESCC Detail Specifications for LEO orbit cable designs.

CABLE DESIGN AND CHARACTERISTICS

All conductors are conventionally concentric stranded silverplated oxygen free copper or silver-plated copper alloy (for AWG 24 and smaller) with silver coating thickness on strands minimum 2 microns. Shield strands are oxygen free copper with minimum 2.5 microns silver plating to minimize the risk of “red plague” corrosion.
Finished wires are composed of two independent wrapped insulation layers, each made of thin resistant low outgassing Fluoropolymer (TRF) tape. 21 variants from AWG 16 to 28 single wires, unshielded and shielded pairs, 3 core and 4 core shielded versions have been qualified following the ESCC 20100 Qualification procedure. Multicore variants include color coding for respective easy cable core identification. [5]
Development objectives described above required to maintain heritage products operating voltage up to 600V rms and operating temperature range from -200°C to +200°C and an appropriate level of mechanical robustness using ATOX resistant Fluoropolymer materials only.

EVALUATION

Evaluation Test Plan (ETP) identified 3 different variants to represent a diverse range of the product. Variant No.6 single wire with AWG 16, 19 stranded silver-plated copper conductor, Variant No 11 shielded twisted pair with AWG 28, 7 stranded silver-plated copper alloy conductors and Variant No 14 shielded twisted pair with AGW22, 19 stranded silver-plated copper conductors have been selected and manufactured according to predefined Process Identification document (PID). Final Inspection Test results acc. to ESCC3901 Chart II for those selected variants is summarized and compared to specification values in Figure 1.



ESCC 3901 Para.	Test Description	Variant No 14 LEW 21-22-C		Variant No 11 LEW 21-28-C		Variant No 06 LEW 10-16-N	
		Measured	*Specified*	*Measured*	*Specified*	*Measured*	*Specified*
9.1	External Visual Inspection	OK	see 9.1	OK	see 9.1	OK	see 9.1
9.2	Weight	11,7 g/m	max. 12,6 g/m	5,3 g/m	max. 5,9 g/m	12,9 g/m	max. 13,5 g/m
9.3	Dimensions cond. strands con. diam. out. Dia.	OK max. 0,74 mm 19 av. 0,15 mm max 2,28 mm	OK Max. 0,76 mm 19 nom 0,15 mm max 2,45 mm	OK max. 0,38 mm 7 av. 0,124 mm max 1,60 mm	OK Max. 0,39 mm 7 nom 0,127 mm max 1,75 mm	OK max. 1,46 mm 19 av. 0,3 mm max 1,66 mm	OK Max. 1,49 mm 19 nom 0,3 mm max 1,8 mm
9.4	Coating	OK OK	OK OK	OK OK	OK OK	OK OK	OK OK
9.5	Conductor Resistance	51,1 Ohm/km	Max. 63 Ohm/km	210,1 Ohm/km	Max. 258 Ohm/km	13,2 Ohm/km	Max. 14 Ohm/km
9.6	Spark	OK	@ 1,0kV rms	OK	@ 1,0kV rms	OK	@ 2,5kV rms
9.7	Voltage	a. OK b. OK b. OK	@ 1,0kV rms @ 3,5kV DC @ 3,5kV DC	a. OK b. OK b. OK	@ 1,0kV rms @ 3,5kV DC @ 3,5kV DC	a. OK	@ 2,5kV rms
9.8	Insulation Resistance	a. OK b. OK	>30MΩ km >750MΩ km	a. OK b. OK	>30MΩ km >750MΩ km	a. OK	>750MΩ km
9.9	Stripping Capability	OK	See 9.9	OK	See 9.9	OK	See 9.9
9.10	Anthony and Brown	0 0	cond. 0-3 Sh. 0-3	0 0	cond. 0-3 Sh. 0-3	1	cond. 0-3
4.4	Marking	OK	See 4.4	OK	See 4.4	OK	See 4.4

Figure 1 ESCC 3901 Chart II Inspection results for 3 selected Evaluation cable variants
Remark: Deviating from ESCC 3901, Para 9.10 Anthony & Brown Qualification resp LAT1 test level is handled as a Final Production Test, due to GORE’s internal enhanced requirements

Heritage Evaluation test programs for new designs have required full Qualification according to ESCC 3901 Chart IV and constructional analysis for each of the selected variants only.
Traditionally ETPs did not consider any step-stress or steady state stress testing designed to determine failure modes and to establish the margins between strength and the specified conditions for use as required by ESCC22600 Para 8.3.
Present ETP was the first one that suggested some specific stress loads for individual evaluation tests and GORE collaborated with DLR technical advisors to define the ETP in a way, that it can offer some foundation and best praxis for future ESA cable stress evaluation guidelines. Figure 2 marks up these stress level tests defined beyond regular operational limits and added to ETP with red text.

ESCC 3901 Para.	**Test Description**	**Variant No 14 LEW 21-22-C**		**Variant No 11 LEW 21-28-C**		**Variant No 06 LEW 10-16-N**	
		Measured	*Specified*	*Measured*	*Specified*	*Measured*	*Specified*
9.11	Mechanical Properties of Conductor	min 19,5%	min. 10%	min 6,8% min 38,4 kg/mm²	min. 6% 35 kg/mm²	min 19,9%	min. 10%
9.12	Accelerated Ageing	OK OK OK	25 mm, 700g; c-c 1,5 kV AC/1 min c-s 1,5 kV AC/1 min s-w 1,5 kV AC/1 min 120h, 230°C 120h, 240°C 120h, 250°C	OK OK OK	10 mm, 500g; c-c 1,5 kV AC/1 min c-s 1,5 kV AC/1 min s-w 1,5 kV AC/1 min 120h, 230°C 120h, 240°C 120h, 250°C	OK OK OK	15 mm, 500g; 10 mm, 500g; 2,5 kV AC/1 min 120h, 230°C 120h, 240°C 120h, 250°C
9.15	Shrinkage Test	max. 0,1 mm max. 0,1 mm max. 0,1 mm	max 2,0 mm 6h @ 200°C 6h @ 210°C 6h @ 230°C	max. 0,0 mm max. 0,0 mm max. 0,0 mm	max 2,0 mm 6h @ 200°C 6h @ 210°C 6h @ 230°C	max. 0,2 mm max. 0,2 mm max. 0,3 mm	max 2,0 mm 6h @ 200°C 6h @ 210°C 6h @ 230°C
9.16	Blocking	OK OK OK	25mm 6h, 230°C 6h, 240°C 6h, 250°C	OK OK OK	10mm 6h, 230°C 6h, 240°C 6h, 250°C	OK OK OK	15mm 6h, 230°C 6h, 240°C 6h, 250°C
9.17	Cold Bend	OK OK	300g ,4h@ -80°C 2,5KV AC 8 mm 6 mm	OK OK	250g ,4h@ -80°C 2,5KV AC 6 mm 4 mm	OK OK	500g ,4h@ -80°C 2,5KV AC 10 mm 8 mm
9.18	Cut-Through Resistance	av. 61,66 N	av. min 45 N	av. 21,94 N	av. min 14 N	av. 47,99 N	av. min 46 N
9.19	Notch Resistance	OK	See 9.19 6 mm	OK	See 9.19 3,5 mm	OK	See 9.19 6 mm
9.21	Resistance to Fluids	OK OK 2,66% max (a)	10mm, 300g 2,5kV AC/1 min <5%	*Evaluation by similarity Not performed on these variants*			
9.22	Surface Resistance	min 5,5 10^{12} Ω mm min 2,9 10^{10} Ω mm min 1,2 10^{10} Ω mm	min 125 MΩ mm 96h @22°C 96h @25°C 96h @28°C	min 9,3 10^{09} Ω mm min 6,8 10^{09} Ω mm min 3,3 10^{09} Ω mm	min 125 MΩ mm 96h @22°C 96h @25°C 96h @28°C	min 2,4 10^{13} Ω mm min 1,1 10^{14} Ω mm min 6,9 10^{13} Ω mm	min 125 MΩ mm 96h @22°C 96h @25°C 96h @28°C
9.23	Abrasion Resistance	min. 262 cycles min. 555 cycles min. 257 cycles	min. 100 cycles @380g @390g @410g	min. 549 cycles min. 498 cycles min. 383 cycles	min. 100 cycles @270g @280g @300g	min. 364 cycles min. 261 cycles min. 267 cycles	min. 100 cycles @450g @460g @480g
9.24	Soldering Shrinkage	max. 0,2 mm max. 0,3 mm max. 0,4 mm	max. 1,5mm 5s @ 320°C 5s @330°C 5s @340°C	max. 0,1 mm max. 0,4 mm max. 0,4 mm	max. 1,5mm 5s @ 320°C 5s @330°C 5s @340°C	max. 0,4 mm max. 0,3 mm max. 0,3 mm	max. 1,5mm 5s @ 320°C 5s @330°C 5s @340°C
9.25	Solderability	con. OK sh. OK	See 9.25 5s @235°C	con. OK sh. OK	See 9.25 5s @235°C	con. OK sh. OK	See 9.25 5s @235°C
9.26	Radiation Resistance	9.7a OK 9.7a OK	after 1,49 MRad after 2,66 MRad	*Evaluation by similarity Not performed on these variants*			
9.27	Overload Resistance	OK	See 9.27				
9.28	Long-Term Ageing	OK OK OK	25 mm, 700g c-s 1,5kV AC/1 min c-s 1,5kV AC/1 min 2000h @ 200°C 2000h @ 210°C 2000h @ 230°C				

Figure 2 Evaluation Test Program and results according to ESCC 3901 Chart V including additional stress tests marked with red text

Intention for stress load selection was originally to select a medium stress level where it assumed to observe initial degradation and an extreme level where samples are expected to fail. To realize a good balance of practical effort, distinct and repeatable stress conditions, it was decided to increase stress by

higher temperature levels and harsher mechanical load on those tests, that do not test to fail by standard test conditions.
Some tests have been rated as not suitable for increased stress level introduction as not linked to any practical needs (e.g. solderability) or just ending up with larger sample to sample variation phenomena in a subsequent test (e.g. resistance to fluids).
For Para 9.17 cold bend test enhanced temperature stress was not feasible due to limited test capability. There is no equipment available providing enough volume to perform Para 9.17 test procedure at temperatures lower than -80°C. Therefore, mechanical load could be increased only.

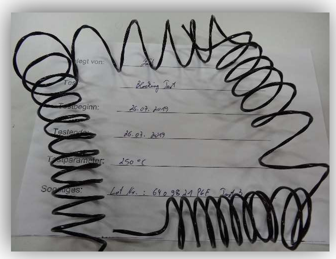


Figure 3 ESCC 3901 Para 9.16 Blocking Test variant 14 sample after 250°C treatment

Figure 4 ESCC 3901 Para 9.17 Cold bend Test variant 14 sample after -80°C exposure

Figure 5 ESCC 3901 Para 9.28 Long Term Aging Test variant 14 sample after 2000h at 230°C

Figures 6 to 9 show some mechanical performance examples out of Evaluation test report for ESCC 3901 Para 9.18 Cut-Through Resistance and Para 9.23 Abrasion Resistance.

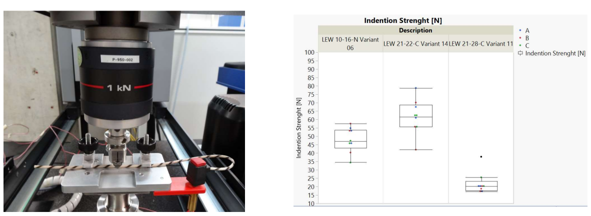


Figure 6 ESCC 3901 Para 9.18 Evaluation variants' Cut-Through Indention strength for 3 samples (A, B, C) per variant and 3 different positions (shifted 75 mm and turned 120°) per sample

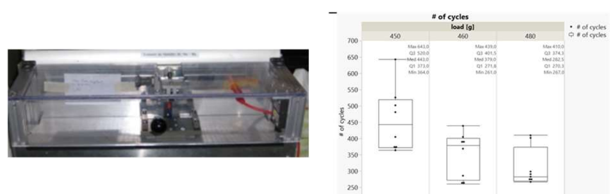


Figure 7 ESCC 3901 Para 9.23 Abrasion Resistance number of cycles for variant No 06 performed with different weight loads and on 2 samples, 4 different positions per sample (shifted 100 mm and turned 90°)

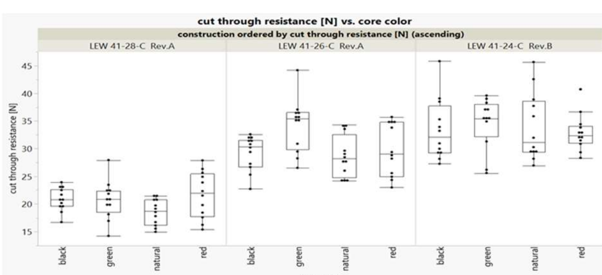


Figure 8 ESCC 3901 Para 9.18 Cut-Through Indention strength for 3 different 4 core twisted shielded pair variants; 4 samples per cable core and 3 different positions (shifted 75 mm and turned 120°) per sample

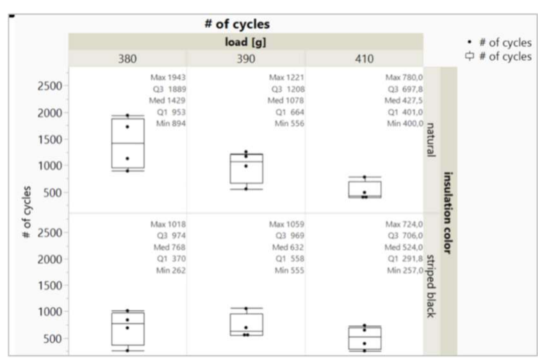


Figure 9 ESCC 3901 Para 9.23 Abrasion Resistance number of cycles for variant No 06 performed with different weight loads per core wire, 2 samples each, 4 different positions per sample (shifted 100 mm and turned 90°)

To evaluate mechanical core to core variability for the multicore variants the evaluation test plan did also consider tests on additional 4 core shielded variants 19 to 21. Figure 8 clearly indicates uniform cut-through Indention strength results independent from core wire. Values on the upper end are correlating with indenter positions on top of a color stripe with high probability.
Cut through and abrasion test results always represent a “system” answer, combining influence of indenter position, insulation wall thickness and conductor size and stranding underneath. Allover results show uniform and consistent results over wire samples’ radius, AWG size and stranding.
Based on the excellent results of the evaluation test program, all designs and PID were frozen without any changes or corrective actions. Evaluation was approved and new Detail Spec ESC 3901/026 issued by ESCC Executive.

QUALIFICATION

To continue diverse representative strategy Variants No 07 shielded twisted pair AWG 26 19 stranded silverplated copper alloy and No 10 shielded twisted pair AWG 20 19 stranded silverplated copper have been selected out of the 21 variants. Figure 10 shows final inspection test results acc. to ESCC3901 Chart II compared to specification values.

ESCC 3901 Para.	Test Description	Variant No 10 LEW 21-20-C		Variant No 07 LEW 21-26-C	
		Measured	*Specified*	*Measured*	*Specified*
9.1	External Visual Inspection	OK	see 9.1	OK	see 9.1
9.2	Weight	17,3 g/m	max. 19 g/m	6,4 g/m	max. 7,1 g/m
9.3	Dimensions cond. strands con. diam. out. Dia.	OK max. 0,97 mm 19 av. 0,2 mm max 2,7 mm	OK Max. 0,99 mm 19 nom 0,2 mm max 3,0 mm	OK max. 0,46 mm 19 av. 0,1 mm max 1,73 mm	OK Max. 0,47 mm 19 nom 0,1 mm max 1,95 mm
9.4	Coating	OK OK	OK OK	OK OK	OK OK
9.5	Conductor Resistance	31,3 Ohm/km	Max. 35 Ohm/km	141,5 Ohm/km	Max. 170 Ohm/km
9.6	Spark	OK	@ 1,5kV rms	OK	@ 1,5kV rms
9.7	Voltage	a. OK b. OK b. OK	@ 1,0kV rms @ 3,5kV DC @ 3,5kV DC	a. OK b. OK b. OK	@ 1,0kV rms @ 3,5kV DC @ 3,5kV DC
9.8	Insulation Resistance	a. >100 GΩ km b. >49 GΩ km	>30MΩ km >750MΩ km	a. >12,5 GΩ km b. >500 GΩ km	>30MΩ km >750MΩ km
9.9	Stripping Capability	OK	See 9.9	OK	See 9.9
9.10	Anthony and Brown	1 0	cond. 0-3 Sh. 0-3	0 0	cond. 0-3 Sh. 0-3
4.4	Marking	OK	See 4.4	OK	See 4.4

Figure 10 ESCC 3901 Chart II Inspection Results for 2 selected Qualification cable variants
Remark: Deviating from ESCC 3901, Para 9.10 Anthony & Brown Qualification resp LAT1 test level is handled as a Final Production Test, due to GORE’s internal enhanced requirements

Figure 11 summarizes the entire Qualification parameters and results that have been reported to ESA. Both variants have proven to meet all requirements

ESCC 3901 Para.	Test Description	Variant No 10 LEW 21-20-C		Variant No 07 LEW 21-26-C Lot No. 6932808PLF	
		Measured	*Specified*	*Measured*	*Specified*
9.11	Mechanical Properties of Conductor	min 19,9%	min. 10%	min 7,7% min 37,6 kg/mm²	min. 6% 35 kg/mm²
9.12	Accelerated Ageing	OK	25 mm, 800g; c-c 1,5 kV AC/1 min c-s 1,5 kV AC/1 min s-w 1,5 kV AC/1 min 120h, 230°C	OK	15 mm, 500g; c-c 1,5 kV AC/1 min c-s 1,5 kV AC/1 min s-w 1,5 kV AC/1 min 120h, 230°C
9.15	Shrinkage Test	max. 0,1 mm	max 2,0 mm 6h @ 200°C	max. 0,1 mm	max 2,0 mm 6h @ 200°C
9.16	Blocking	OK	25mm 6h, 230°C	OK	15mm 6h, 230°C
9.17	Cold Bend	OK	400g ,4h@ -80°C 2,5KV AC 8 mm	OK	250g ,4h@ -80°C 2,5KV AC 6 mm
9.18	Cut-Through Resistance	av. min 53,6 N	av. min 46 N	av. min 30,8 N	av. min 23 N

ESCC 3901 Para.	Test Description	Variant No 10 LEW 21-20-C		Variant No 07 LEW 21-26-C	
		Measured	*Specified*	*Measured*	*Specified*
9.19	Notch Resistance	OK	See 9.19 7 mm	OK	See 9.19 4 mm
9.22	Surface Resistance	min 30,1 10^{12} Ω mm	min 125 MΩ mm 96h @22°C	min 8,7 10^{12} Ω mm	min 125 MΩ mm 96h @22°C
9.23	Abrasion Resistance	min. 216 cycles	min. 100 cycles @440g	min. 665 cycles	min. 100 cycles @330g
9.24	Soldering Shrinkage	max. 0,3 mm	max. 1,5mm 5s @ 320°C	max. 0,3 mm	max. 1,5mm 5s @ 320°C
9.25	Solderability	con. OK sh. OK	See 9.25 5s @235°C	con. OK sh. OK	See 9.25 5s @235°C
9.27	Overload Resistance	OK	See 9.27	OK	See 9.27
9.28	Long-Term Ageing	OK	25 mm, 800g c-s 1,5kV AC/1 min c-s 1,5kV AC/1 min 2000h @ 200°C	OK	15 mm, 500g c-s 1,5kV AC/1 min c-s 1,5kV AC/1 min 2000h @ 200°C

Figure 11 Qualification Test Program and Results according to ESCC 3901 Chart V

ESCC 3901 SPECIFICATIONS' ANALOGY

Comparing Specification data of 13 heritage cable types listed on the Qualified Parts List (QPL) according to ESCC 3901 Generic specifications will indicate how newest low earth orbit wire and cable portfolio now qualified to ESCC 3901 and ESCC 3901/026 aligns to existing active framework of table 1(a) Detail specs[6].

Figure 12 shows maximum outer diameter and weight for single unshielded AWG 22 wires across all specifications. Other cable variants will end up with different values, but same relations. x Axis' green markers indicate ATOX resistant insulation materials preferred for use in LEO orbit, brown markers indicate radiation resistant material for use in GEO. Black markers indicate different sets of material for single and multicore wires and need to be aligned by variant individually. For AWG 22 single wire example they will align to preferred GEO orbit use.

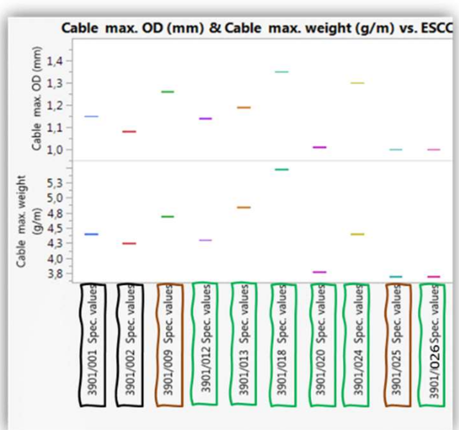


Figure 12 Weight and diameter limit for AWG 22 single unshielded wires

ESCC 3901/026 (LEW)							Corresponding Var. of ESCC 3901/024		LEW compared to ESCC 3901/024		Corresponding Var. of ESCC 3901/020		LEW compared to ESCC 3901/020	
Variant	Shielded Yes	Shielded No	No. of cores	Wire Size AWG	Max diameter [mm]	Max weight [g/m]	Max diameter [mm]	Max weight [g/m]	Max diameter [mm]	Max weight [g/m]	Max diameter [mm]	Max weight [g/m]	Max diameter [mm]	Max weight [g/m]
1		x	1	28	0,62	1,14	0,85	1,70	-27%	-33%	0,63	1,15	-2%	-1%
2		x	1	26	0,71	1,63	1,00	2,20	-29%	-26%	0,75	1,81	-5%	-10%
3		x	1	24	0,83	2,25	1,15	3,10	-28%	-27%	0,87	2,50	-5%	-10%
4		x	1	22	1,00	3,7	1,30	4,40	-23%	-16%	1,01	3,78	-1%	-2%
5		x	1	20	1,25	6,2	1,55	7,40	-19%	-16%	1,26	6,31	-1%	-2%
6		x	1	16	1,8	13,5	2,20	17,00	-18%	-21%	1,90	14,05	-5%	-4%
7		x	2	26	1,45	3,4	2,00	4,60	-28%	-26%	1,50	3,73	-3%	-9%
8		x	2	24	1,8	4,9	2,30	6,50	-22%	-25%	1,74	5,15	3%	-5%
9		x	2	22	2,2	7,6	2,60	9,20	-15%	-17%	2,02	7,79	9%	-2%
10		x	2	20	2,5	12,7	3,10	15,50	-19%	-18%	2,52	13,00	-1%	-2%
11	x		2	28	1,75	5,9	2,30	8,50	-24%	-31%	2,06	7,71	-15%	-23%
12	x		2	26	1,95	7,1	2,60	10,00	-25%	-29%	2,31	9,86	-16%	-28%
13	x		2	24	2,2	9,0	2,90	12,50	-24%	-28%	2,55	11,97	-14%	-25%
14	x		2	22	2,45	12,6	3,20	16,00	-23%	-21%	2,85	15,64	-14%	-19%
15	x		2	20	3,0	19,0	3,70	24,20	-19%	-21%	3,35	22,39	-10%	-15%
16	x		3	28	1,85	7,9	2,40	10,60	-23%	-25%	2,16	10,10	-14%	-22%
17	x		3	26	2,05	9,0	2,80	12,70	-27%	-29%	2,43	13,15	-16%	-32%
18	x		3	24	2,3	11,3	3,10	15,90	-26%	-29%	2,69	16,25	-14%	-30%
19	x		4	28	2,0	9,1	2,60	13,00	-23%	-30%	2,32	12,26	-14%	-26%
20	x		4	26	2,2	11,0	3,00	15,70	-27%	-30%	2,61	16,15	-16%	-32%
21	x		4	24	2,4	14,3	3,40	20,20	-29%	-29%	2,91	20,13	-18%	-29%

Figure 13 Weight and diameter limits for all variants of ESCC 3901/026 compared to ESCC 3901/024 and ESCC 3901/020

New variant is lightest and thinnest for LEO orbit preferred use and on par with GORE's ESCC 3901/025 CSC type cables, which are lightest and thinnest for GEO use. Figure 12 also indicates that closest alternative regarding weight and diameter is ESCC 3901/020, therefore Figure 13 compares relative numbers of all variants individually. As ESCC 3901/020 is an extruded single layer design, ESCC 3901/024 cable is also added as a dual layer design representative to the full comparison.
Based on those date the initial product concept claim of having qualified lightest and thinnest LEO cable variant is confirmed. Moreover, there can be identified only two exceptions in diameter, if comparison with lightest single insulation layer designs according to ESCC 3901/020 tolerated.

To collate mechanical performance characteristics of the extremely thin insulation layers tables in Paragraphs 4.8.8 and 4.8.13 of the individual Detail Specifications can provide some guidance. Again AWG 22 single wire example will be used to provide some numbers illustrating general relations that could be verified on other variants in the same way.

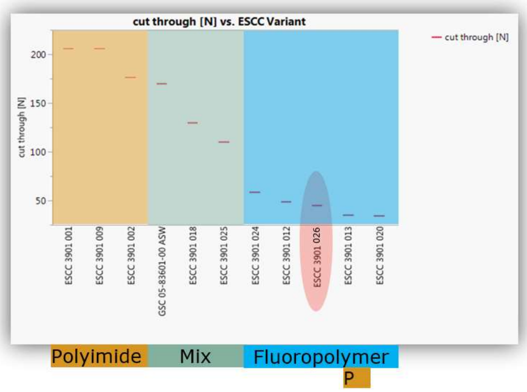


Figure 14 ESCC 3901 Para 9.18 minimum Cut-Through Indention strength limit [N]

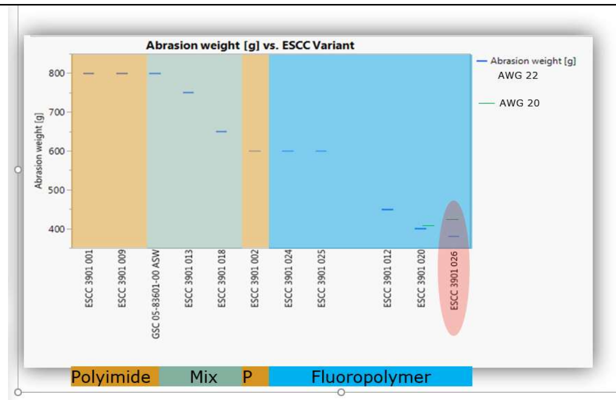


Figure 15 ESCC 3901 Para 9.23 Specified Abrasion weight load to reach min 100 abrasion cycles to electrical shortage

Comparing minimum indention strengths that must be achieved in ESCC 3901 Para 9.18 cut through tests, one will find that ESCC 3901/026 guaranties about 30% higher value compared to other light weight fluoropolymer material-based variants (Figure 14).
Specified abrasion load weights for ESCC 3901 Para 9.23 abrasion test are about 5% lower for AWG 22 and about 10% higher for AWG 20 when ESCC 3901/026 is compared to adjacent ESCC 3901/020 (Figure 14).
It's not possible to do to a ranking based on those information's only. Additional information about number of cycles achieved under those test conditions to provide clarity is not available. As differences are small, one can only assume they will end up in a comparable range.

CONCLUSION

As one could see in Figure 2 evaluation results columns even the extreme stress levels have not led to any fail result as intended originally. Stress test plan has been too conservative obviously or in other words, margins to fail have been proven to be surprisingly high. A real test to fail test program will require to increase stress levels if this is going to be evaluated in future. However, this evaluation debuting enhanced stress level testing created a baseline for future stress test evaluation for ESCC 3901 category wires and cables.

Qualification has performed and certified without any changes to designs or PID after evaluation. Detail Specifications' comparisons provide proof of evidence that ESCC 3901/026 offers the lightest and thinnest wire and cable portfolio certified by ESCC executive.

ACKNOWLEDGMENTS

The authors acknowledge with gratitude the support from ESA, DLR and their technical advisors from TESAT EEE parts agency. Special thanks to Denis Lacombe (ESA) for fruitful feedback and organizing the constructional analysis, Itziar Hoces Fernandez (ESA) for performing the constructional analysis, Burak Gökgöz (DLR) for maintaining appropriate contacts and managing the overall structure that helped us to focus.

Finally we really appreciate all the support from Jürgen Riedinger and Anita Weinschrott-Schaaf (TESAT), guiding us to the ESCC20110 qualification process in detail, challenging us in the review meetings and consistently supported our frequent questions with patience and in time.

REFERENCES

[1] R. R. Roe, "Spacecraft Polymers atomic Oxygen Durability Handbook," National Aeronautics and Space Administration, Washington, DC, 2014.

[2] Kim K. de Groh, Bruce A. Banks, Catherine E. McCarthy, Rochelle N. Rucker, "MISSE PEACE Polymers Atomic Oxygen Erosion Results," NASA, Cleveland, Ohio, 2006.

[3] European Space Agency, "ESCC 3901 Generic Specification for Wires and Cables Electrical 600V Low Frequency Issue 3," January 2017. [Online]. Available: https://escies.org/specification/listpubspecs?pubcode=25&family=6. [Accessed 22 July 2022].

[4] European Space Agency, "ESCC Detail Specification No. 3901/026 Issue 1," August 2020. [Online]. Available: https://escies.org/specification/listpubspecs?pubcode=25&family=6. [Accessed 22 July 2022].

[5] European Space Agency, "Requirements for Qualification of Standard Electronic Components for Space Application issue 5," June 2016. [Online]. Available: https://escies.org/specification/listpubspecs?pubcode=1&family=1. [Accessed 22 July 2022].

[6] European Space Agency, "Qualified Parts List (REP 005)," May 2022. [Online]. Available: https://escies.org/download/downloadRep005. [Accessed 29. July 2022].