Abrasion Resistance of Insulated Wire in a Metalized Environment (Phase II)

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Abstract

Polytetrafluoroethylene (PTFE) and cross-linked ethylene-tetrafluoroethylene (XL-ETFE) have been used as high temperature insulation materials for aerospace wire and cable applications for several decades. Industry has reported shortened installation life of XL-ETFE insulated wire in high temperature/high vibration environments when metalized protection is required. This metalized protection includes metal connectors and backshells as well as metal overbraid. The premature failure of this insulation system led to a comparative evaluation of M22759/41-20 medium weight XL-ETFE and M22759/87-20 medium weight PTFE/polyimide insulated wire in Phase I of this test program. Phase II of this evaluation will examine the relative abrasion performance of a revise formulation of ***Seamless*** PTFE which will be called ***Seamless-T*** (for toughened PTFE) along with constructions manufactured with T60 and 613A PTFE tapes

Introduction

The use of XL-ETFE insulated wire has been successfully applied to aerospace vehicles for several decades. Relatively few issues were reported with this material when used at lower temperatures. As higher temperature applications were introduced which approached the 200ºC thermal rating of the insulation system, premature failures were observed. This paper will examine one specific case where the insulation failure was a result of poor abrasion resistance and mechanical robustness in the severe environment of high temperature and high vibration when the insulated wire was protected by a metalized environment for EMI/EMP purposes.

Evaluation (Wire to Conductor Method)

The mechanical robustness of the insulation system at ambient and elevated temperatures is critical to system performance. Insulation systems with poor abrasion resistance and cut-though characteristics at high temperatures increase the probability of chaffing, tearing and cutting the insulation surface exposing the conductor to the environment. The effective temperature of the insulation system is affected both by environmental conditions and thermal heating of the conductor due to the resistive heating effect. An increased propensity for damage will result in increased number of maintenance actions and a higher probability of system failure during abnormal events such as over-current, electrical arcing or fire conditions.

Abrasion resistance to metal shields, backshells and connectors at ambient and elevated temperatures can be examined using a modified wire-to-wire test fixture with a metal shroud over the specimens under test to achieve the desired temperature profile.

The wire-to-wire abrasion test has been utilized by the major commercial aircraft manufacturers in the United States (Boeing-Seattle and Boeing-Long Beach) since the mid-1970's to examine the issue of wire-to-wire chaffing of installed bundles in the airframe. The test was introduced to provide a high level of confidence that the insulation system chosen for that particular aircraft application would not deteriorate in a moderate to high vibration environment over the expected life of the airframe.

The actual test method requires two wires to be mounted in an oscillating fixture. Specimen A, with a length of 24 inches, is mounted to the oscillating fixture at one end and the other end is routed over a pulley with a prescribed weight attached. Specimen B, with a length of 12 inches, is attached to the fixture at both ends. The relative displacement between the oscillating plates is 0.25 ± 0.01 inches and the oscillating frequency is 10 cycles per second. A sketch of the required fixture is shown in Figure I.

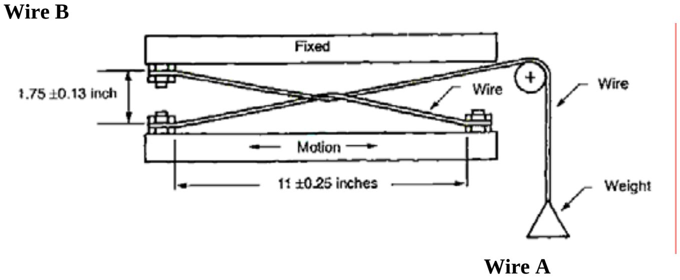

Figure I. Test Fixture

The insulation wear occurs at the point where the two wires are twisted around each other with the weight attached to specimen A providing the compressive force to initiate the degradation. By increasing or decreasing the weight applied, the rate of degradation will increase or decrease. Since the purpose of this evaluation is to characterize the relative abrasion resistance between an insulated wire and a metal braid, the specimen A location was populated with the wire under test and the specimen B location was populated with an uninsulated 19 strand, 20 gauge, nickel plated copper conductor.

Temperature profiles at ambient (23°C), 150°C, 200°C and 260°C were examined based on the accepted thermal ratings of wire and cable products used in aerospace vehicles. Based on the consistent results from the Phase I evaluation a load of 5.0 pounds was used at each of the thermal conditions evaluated. Five different test specimens were evaluated using this test methodology. The first four were M22759/87-20-9 (medium wall) PTFE/polyimide insulated wires using Thermax ***Seamless*** PTFE, Thermax ***Seamless-T*** PTFE, T60 grade PTFE and 613A grade PTFE. The final specimen tested was a M22759/41-20-9 XL-ETFE insulated wire.

Test Apparatus

The original test fixture was developed for standard wire-to-wire abrasion testing at ambient conditions. The apparatus allows for up to 10 specimens to be evaluated in parallel. A unique digital counter is attached to each specimen combination for ground detection. All of the specimens under test start at the same time. As ground paths are detected on each specimen pair, the respective counter is disabled holding the cycles to failure data, while the remaining specimens continue their respective cycle to failure. A picture of the test apparatus is shown in Photo I.

The digital counters are located above the specimens under test in the electronics housing. The frequency control for the oscillation rate is located directly below the digital counters and is displayed in cycles per minute. To meet oscillation requirement of 10 cycles per second, the fixture was adjusted to 600 cycles per minute. The actual rate of oscillation varied from 590 to 610 cycles per minute during the course of the longest individual test cycle. Photo II. depicts how the specimens were routed and the weights attached.

Photo I. Test Apparatus

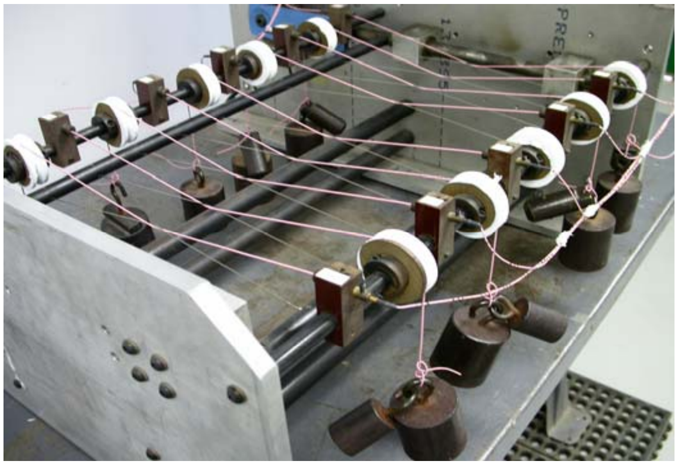

Photo II. Mounted Specimens

Abrasion at Ambient

The original wire-to-wire test was modified slightly to incorporate the uninsulated conductor in the specimen B location, which is shown in Photo III. The uninsulated conductor in the specimen B location (bottom wire) and the specimen under test (top wire).

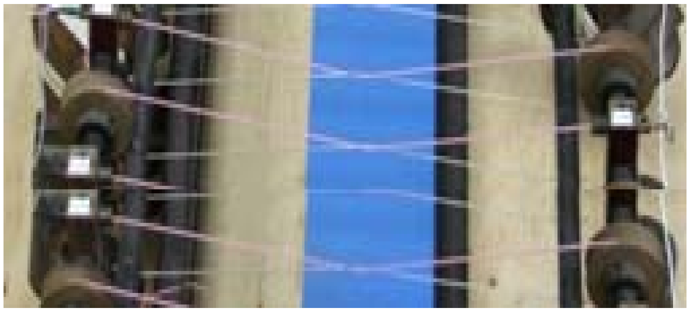

Photo III. Specimen Location

The test protocol requires that four wire specimens are placed in fixture locations C7, C8, C9 and C10 which are the last four mounting locations on the test fixture. A load of 5.0 pounds was attached to each specimen. The oscillation cycle was initiated and continued until the last specimen failed. The test was repeated a total of three times (twelve samples total), with the highest and lowest readings discarded and the remaining ten readings were recorded and averaged. This process was repeated for all five wire specimens. Photo IV depicts the typical abrasion damage caused by the uninsulated wire.

Photo IV. M22759/41-20 Specimen

The average cycles to failure at ambient were significantly different for the five constructions evaluated. Table I displays the actual results along with the average, minimum reading, maximum reading and statistical mean for each of the five specimens tested. The five specimens are identified as follows:

Std Seam: Thermax Original ***Seamless*** PTFE
Seam T: Thermax Improved ***Seamless*** PTFE
T60: T60 Grade PTFE Tape
613A : 613A Grade PTFE Tape
XL-ETFE: M22759/41-20 XL-ETFE

20 AWG Cond (23C, 5.0 pounds)					
	Std Seam	**Seam T**	**XL-ETFE**	**T60**	**613A**
1	302947	6188944	72774	613597	959743
2	489104	7324711	22506	785798	972863
3	498807	3621781	26224	596578	651862
4	421321	4620656	43213	434563	419262
5	398743	3709202	38642	707295	848164
6	376549	2931788	67432	891299	576110
7	401231	2983228	54325	844630	460576
8	324294	6215197	39213	757038	851441
9	309231	4321321	29349	698395	737291
10	489659	4890784	31996	721327	684393
AVG	401189	4680761	42567	705052	716171
MIN	302947	2931788	22506	434563	419262
MAX	498807	7324711	72774	891299	972863
MEAN	399987	4470989	38928	714311	710842

Table I. Wire-Conductor Results at Ambient

Figures IIa and IIb (log scale) display the average cycles to failure for the five constructions.

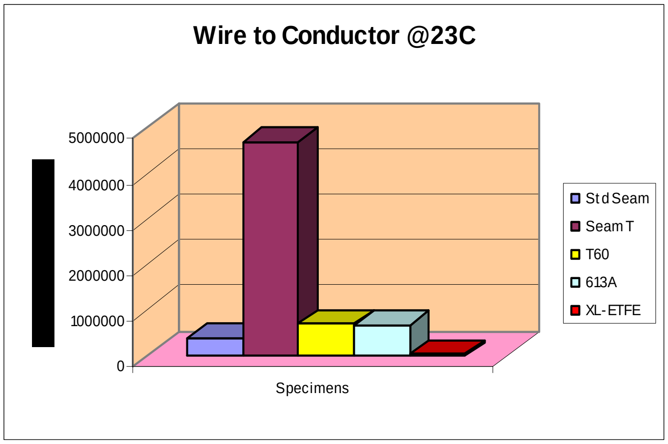

Figure IIa. Wire-Conductor Results at Ambient

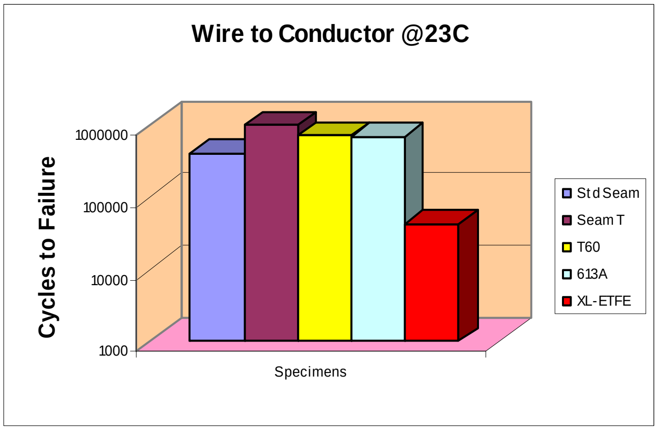

Figure IIb. Ambient (Log Scale)

At ambient temperatures, the ***Seamless-T*** construction survived an order of magnitude more cycles than the original ***Seamless*** PTFE formulation and six to seven times as many cycles as the standard T60 and 613A tapes. The XL-ETFE construction was the poorest performer with a ten to one hundred times fewer cycles than the other four products. Since abrasion testing tends to follow logarithmic progressions, the original ***Seamless*** PTFE, T60 PTFE and 613A PTFE would be considered statistically equivalent materials, while the enhanced performance of the ***Seamless-T*** would be considered significant. The XL-ETFE would be considered statistically inferior to the other four products in this test.

Abrasion at Temperature

The abrasion evaluation at elevated temperatures required a modification of the existing test fixture. The primary modification was the construction of a metal shroud around four of the specimen holders, the addition of a controllable heat source (heat gun) and the installation of three thermal couples to provide constant monitoring of the thermal gradient inside the shroud to ensure all of the specimens were subjected to the same heat profile. Photos V and VI show the installation of the shroud (black enclosure), the heat gun and the thermal couple wires (yellow).

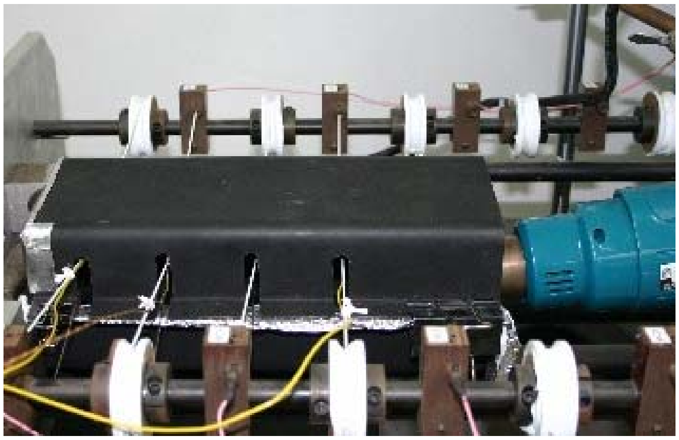

Photo V. Thermal Shroud

Photo VI. Test Fixture for Thermal Testing

Twelve specimens of each construction style were tested at 150°C, 200°C and 260°C with a 5.0 pound load attached. The highest and lowest values were discarded and the ten remaining values were recorded and averaged for each specimen condition and the tabulated results are displayed in Tables II, III and IV. The results at 150°C are shown graphically in Figures IIIa and IIIb (log scale). The results at 200°C are shown graphically in Figures IVa and IVb (log scale) and the results at 260°C are displayed in figures Va and Vb (log scale). The first observation that needs to be noted is that as the fluoropolymer's temperature was elevated, the material migrated into the abrading surface essentially coating the uninsulated conductor with either ETFE or PTFE. Photo VII shows the significant buildup of fluoropolymer on the stranded conductor used as the abrading surface. The coating reduced the surface tension and allowed the specimens to survive longer in the environment.

Photo VIII. Fluoropolymer Buildup

With a load of 5.0 pounds, the effect of this migration was greatly diminished and the results for each construction type were very consistent.

20 AWG Cond (150C, 5.0 pounds)					
	Std Seam	Seam T	XL-ETFE	T60	613A
1	442876	1003249	137038	297108	275722
2	389231	1068403	137908	165347	221084
3	299456	815292	125338	192418	213776
4	156324	381290	175986	283695	273957
5	289321	1171008	130993	244875	287349
6	398674	1032426	149873	258732	225467
7	410934	856565	127384	211684	267431
8	267398	1425721	117621	291560	283258
9	400293	1121027	145367	287648	219342
10	406729	986208	153023	256432	234342
AVG	346124	986119	140053	248950	250173
MIN	156324	381290	117621	165347	213776
MAX	442876	1425721	175986	297108	287349
MEAN	393953	1017838	137473	257582	250887

Table II. Wire-Conductor Results at 150ºC

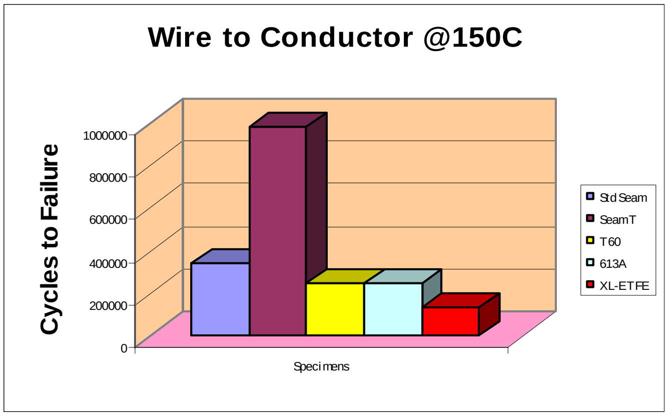

Figure IIIa. Wire-Conductor Results at 150ºC

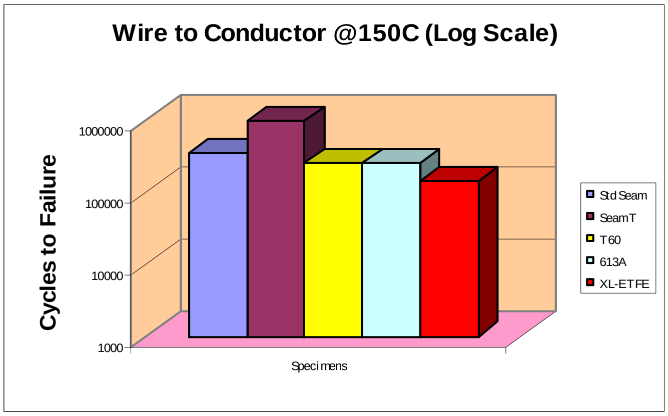

Figure IIIb. 150°C (Log Scale)

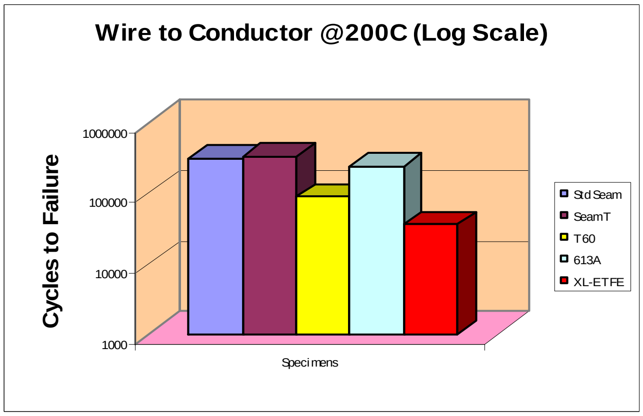

Figure IVb. 200°C (Log Scale)

20 AWG Cond (200C, 5.0 pounds)					
	Std Seam	**Seam T**	**XL-ETFE**	**T60**	**613A**
1	331129	168607	43897	39185	381010
2	316911	161152	59737	43604	92415
3	276254	126233	21886	33083	414749
4	331129	109645	24448	18151	304318
5	320111	879194	31221	132291	95341
6	258395	599464	39753	77261	134935
7	345293	228758	41993	181923	212433
8	312930	229567	27556	145213	234569
9	341119	327841	32641	99456	298341
10	299453	491036	34239	103249	198477
AVG	313272	332150	35737	87342	236659
MIN	258395	109645	21886	18151	92415
MAX	345293	879194	59737	181923	414749
MEAN	318511	229163	33440	88359	223501

Table IV. Wire-Conductor Results at 200°C

20 AWG Cond (260C, 5.0 pounds)					
	Std Seam	**Seam T**	**XL-ETFE**	**T60**	**613A**
1	98441	205751	1004	24445	36742
2	82266	73876	609	15632	17469
3	26682	39365	555	21785	42419
4	59391	58668	356	33241	50185
5	52321	98657	721	11256	50322
6	73452	75341	658	9251	21722
7	68790	103426	459	10459	69406
8	59873	87902	399	12321	55071
9	78923	81993	781	13568	28653
10	81234	96528	643	19876	19844
AVG	68137	92151	619	17183	39183
MIN	26682	39365	356	9251	17469
MAX	98441	205751	1004	33241	69406
MEAN	71121	84948	626	14600	39581

Table V. Wire-Conductor Results at 260°C

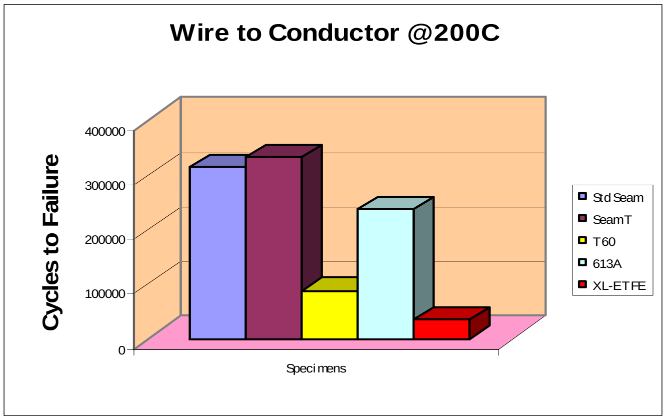

Figure IVa. Wire-Conductor Results at 200°C

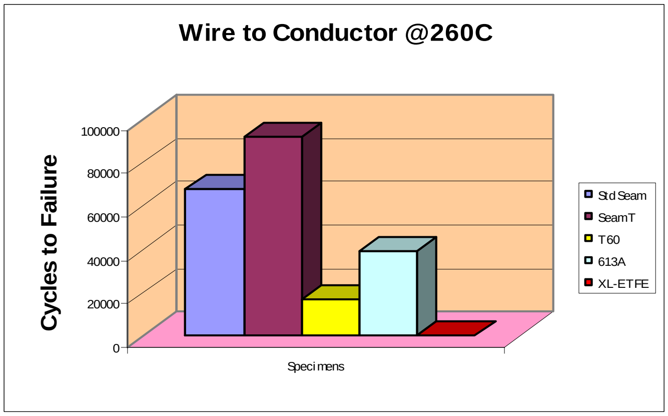

Figure Va. Wire-Conductor Results at 260°C

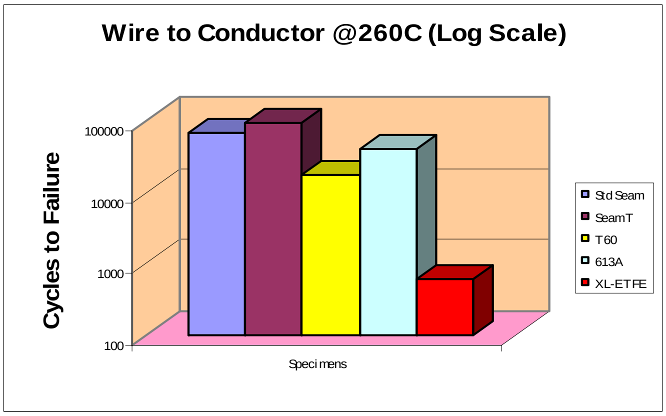

Figure Vb. 260°C (Log Scale)

The data can also be evaluated by comparing the ***Seamless-T*** construction with the performance of the original ***Seamless***, the T60 tape and the 613A tape in a side by side manner and plotting the results on a Log Scale. Figure VI compares the improved ***Seamless-T*** product with the original Thermax ***Seamless*** construction. Figure VII compares the ***Seamless-T*** construction against a product manufactured with the T60 tape and figure VIII compares the ***Seamless-T*** with a construction using the 613A tape.

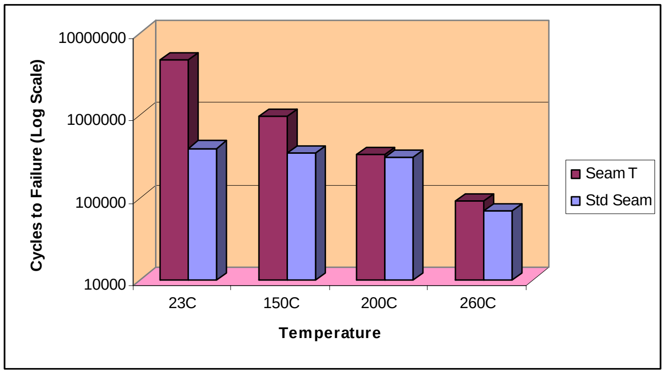

Figure VI. *Seamless-T* vs. Original *Seamless*

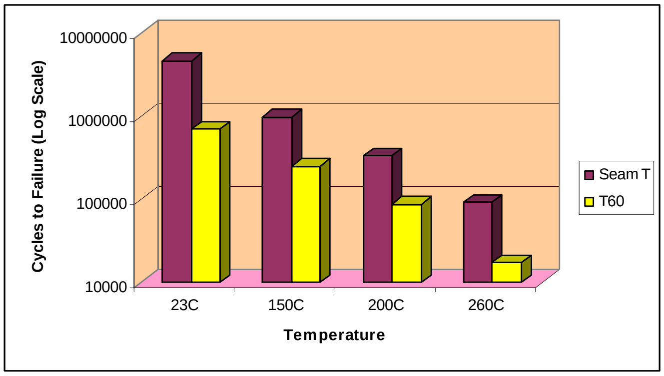

Figure VII. *Seamless-T* vs. T60 Tape

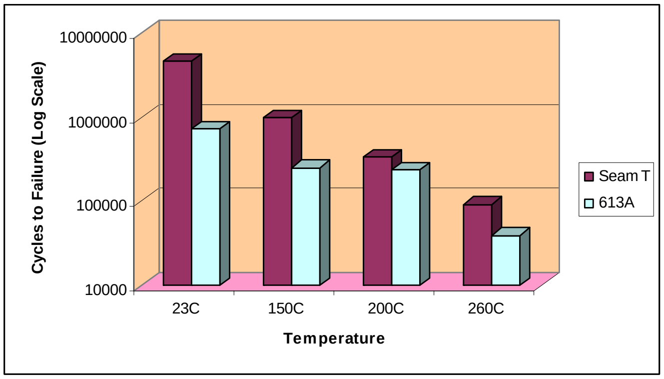

Figure VIII. *Seamless-T* vs. 613A Tape

This test methodology differs from other abrasion methods by applying a relatively hard rough abrasion material against the insulation surface under tension and provides relative movement around the wire. This movement acts like a saw cutting its way through the insulation material. Unlike the needle test, the tension is evenly spread around the wire surface which minimizes deformation of the specimen. The insulating material tends to ablate off the wire in a relatively consistent manner with a high degree of repeatability.

The improved ***Seamless-T*** construction demonstrated clearly superior abrasion resistance when compared to the other PTFE products at temperatures of 150°C and below. This was the initial goal of the formulation change to improve mechanical robustness during harness fabrication and aircraft installation. The superior bond strength between the Oasis film and the PTFE outer layer provides the improved performance over the T60 and 613A tapes at temperatures above 150°C. The T60 tape is clearly inferior to the ***Seamless-T*** product at all temperatures tested, with the ***Seamless-T*** outlasting the T60 film by four to six times as many cycles. While 613A tape performed better than the T60 product, it failed to keep pace with the improved ***Seamless-T*** product at all temperatures tested.

Evaluation (Reciprocating Needle Test)

The reciprocating needle test has been used in the United States for several decades to validate adhesion of marking inks on the surface of an insulated wire. This test method is described in AS4373, method 710 and uses a 0.025 inch needle. The required load and minimum number of cycles are listed in the wire's specification sheet. This method was evaluated in round robin testing in the United States several times in the past 30 years to be considered as an insulation abrasion test. Since the results of the round robin testing were inconclusive and the variability of results was high, the industry decided not to incorporate this test method for abrasion testing.

The European aerospace community had much better results with this test method and incorporated it into several test methods documents including European Norms (EN) and British Standards (BS). British Standard 3G230 Method 31 describes the test method used in Europe and it has become a performance requirement for wire constructions in European platforms.

British Standard 61-12 part 33/008 is the material specification for composite wire in the United Kingdom and is used on several British and European military aerospace platforms. This specification requires a 5.0N load to be applied and to count the number of cycles needed to penetrate the insulating layer using the standard reciprocating needle tester called out in the AS4373 test method. The needle is described as a round dowel with a diameter of approximately 0.020 inches. A cycle consists of moving the needle across the upper surface of the specimen for a distance of approximately 0.5 inches and returning back to the point of origin. This test was performed at ambient (23ºC), 150ºC, 200ºC and 260ºC. Figure IX displays the sketch of the abrasion test fixture from the BS 3G230 test methods document. Details of how the abrading edge is to be mounted into the holding fixture are shown in Figure X.

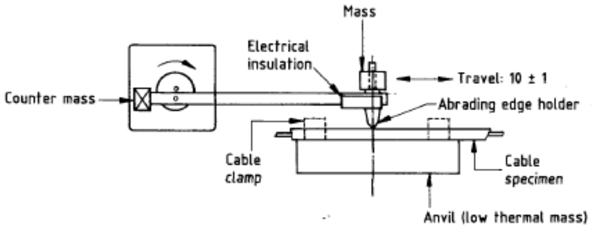

Figure IX. Abrasion Test Fixture

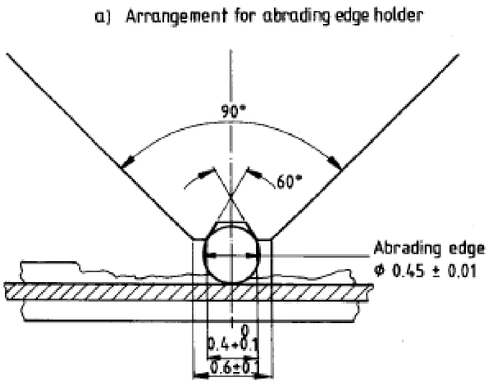

Figure X. Needle Placement

The actual tester used for this evaluation was originally produced by GE. Thermax modified the original fixture to enclose the specimen and allow for elevated temperature testing. Photo VII shows the test apparatus as modified and Photo VIII shows where the specimen is installed along with the placement of the heat gun and thermal couples for elevated temperature testing.

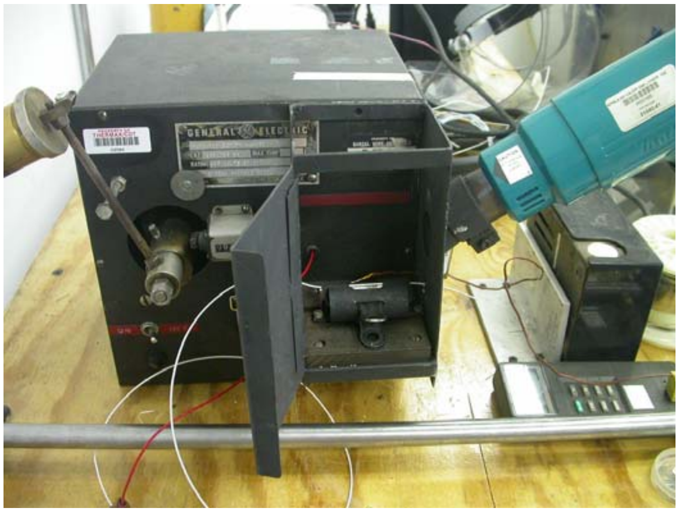

Photo VII. Modified Test Fixture

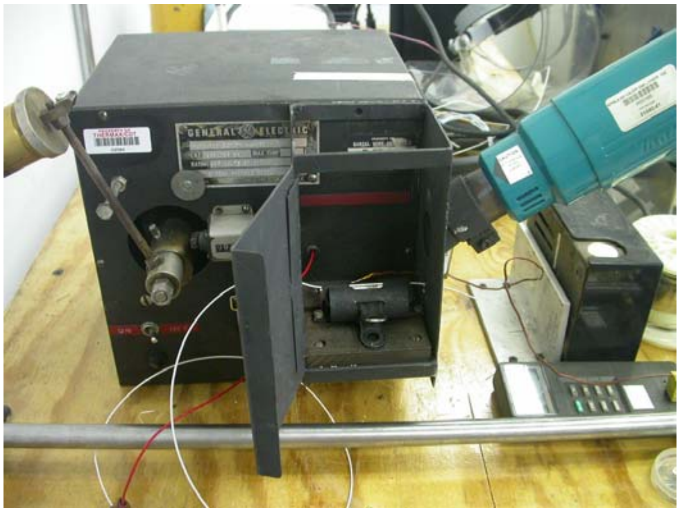

Photo VIII. Specimen Placement

Needle Abrasion Test Protocol

A 30 inch specimen of each of the five wire constructions were prepared by removing a 0.5 inch slug of insulation off of one end and attaching the exposed conductor to the continuity monitoring circuit of the abrasion tester. The specimen was put into place in the wire holder, the counter set to zero and the abrasion head was lowered to touch the wire. The enclosure door was closed and the heat source was adjusted for the proper temperature.

Temperature was monitored and allowed to stabilize for 3 minutes. Once the temperature had stabilized, the tester was turned on allowing the cam driven abrasion needle to rub across the top surface of the specimen under test. The tester monitors for continuity between the specimen’s conductor and the needle. Once continuity is detected, the tester turns off and the number of cycles to penetration were recorded. Twelve readings were taken with the highest and lowest reading discarded. The remaining ten readings were recorded on each wire type at ambient (23ºC), 150ºC, 200ºC and 260ºC. Table VI displays the results at ambient (23°C). The table also includes the average value, the minimum and maximum readings along with the mean value. The average of the ten readings of each specimen style is displayed in Figures XIa and XIb (log scale). The same material legend for construction styles is used in this portion of the paper and is noted below.

Std Seam:	Thermax Original ***Seamless*** PTFE
Seam T:	Thermax Improved ***Seamless*** PTFE
T60:	T60 Grade PTFE Tape
613A :	613A Grade PTFE Tape
XL-ETFE:	M22759/41-20 XL-ETFE

Table VII provides the test results at 150°C, while Tables VIII and IX display the results at 200°C and 260°C respectively. Figures XIIa and XIIb (log scale) display the average results at 150°C for each construction style. Figure XIIIa and XIIIb (log scale) show the average values at 200°C while figures IVXa and IVXb (log scale) depict the average values at 260°C.

	Needle (23C, 5.0 N)				
	Std Seam	**Seam T**	**XL-ETFE**	**T60**	**613A**
1	7114	3314	687	8133	7283
2	6261	18746	1115	9689	10018
3	7535	9892	642	10158	11010
4	8377	17836	1520	7672	6548
5	7794	15161	2001	10630	5513
6	6876	18753	639	5679	6231
7	5734	6429	1345	7852	8294
8	8963	10963	867	9750	6756
9	7541	8013	1037	8821	9379
10	7542	6641	699	7432	6648
AVG	7374	11575	1055	8582	7768
MIN	5734	3314	639	5679	5513
MAX	8963	18753	2001	10630	11010
MEAN	7538	10428	952	8477	7020

Table VI. Needle Abrasion Results at 23°C

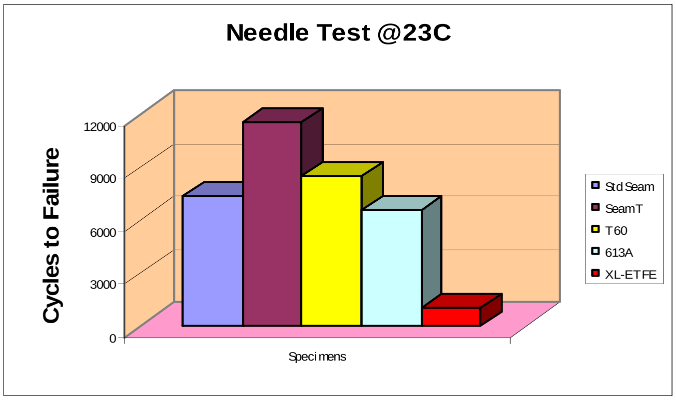

Figure XIa. Needle Results at 23°C

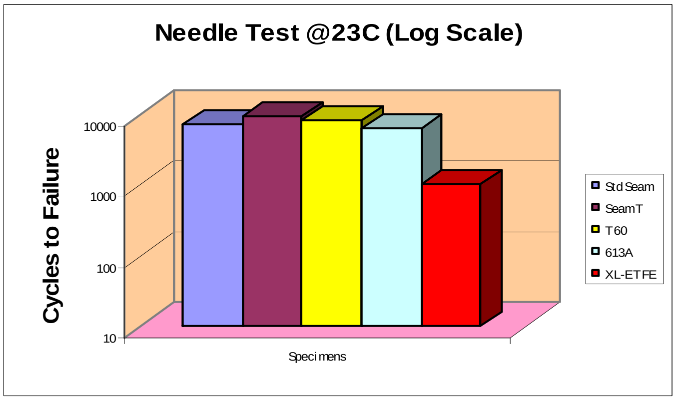

Figure XIb. 23°C (Log Scale)

	Needle (150C, 5.0 N)				
	Std Seam	**Seam T**	**XL-ETFE**	**T60**	**613A**
1	1884	1900	71	1289	1834
2	1271	2820	53	1921	796
3	1240	1205	33	1437	1343
4	1920	2079	73	1521	806
5	2189	1557	56	927	1921
6	1780	2713	28	1345	1121
7	1356	2033	44	1256	988
8	2087	1329	51	1342	1232
9	1818	1302	37	1547	1177
10	1707	1470	48	1159	1314
AVG	1725	1841	49	1374	1253
MIN	1240	1205	28	927	796
MAX	2189	2820	73	1921	1921
MEAN	1799	1729	50	1344	1205

Table VII. Needle Abrasion Results at 150°C

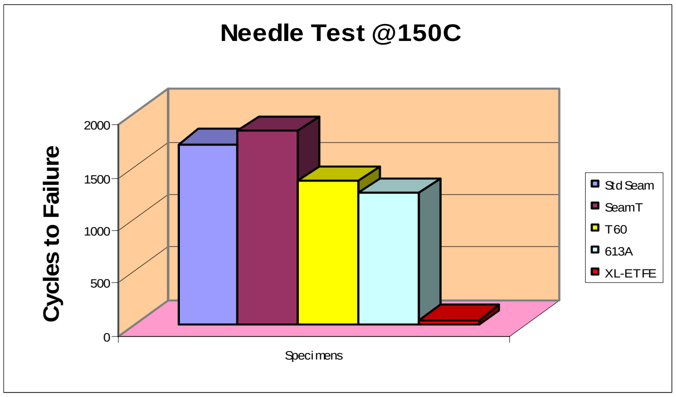

Figure XIIa. Needle Results at 150°C

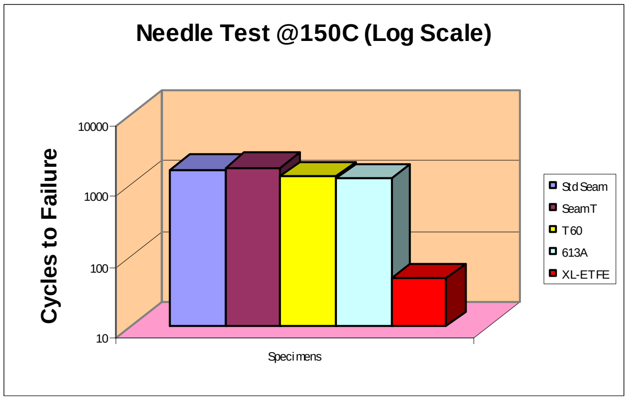

Figure XIIb. 150°C (Log Scale)

	Needle (200C, 5.0 N)				
	Std Seam	**Seam T**	**XL-ETFE**	**T60**	**613A**
1	205	161	5	146	489
2	332	217	5	421	322
3	113	269	4	299	148
4	297	248	5	896	442
5	346	120	5	456	101
6	321	360	5	366	433
7	211	102	4	221	189
8	298	235	5	299	236
9	178	278	5	437	206
10	307	321	4	348	224
AVG	261	231	5	389	279
MIN	113	102	4	146	101
MAX	346	360	5	896	489
MEAN	298	242	5	357	230

Table VIII. Needle Abrasion Results at 200°C

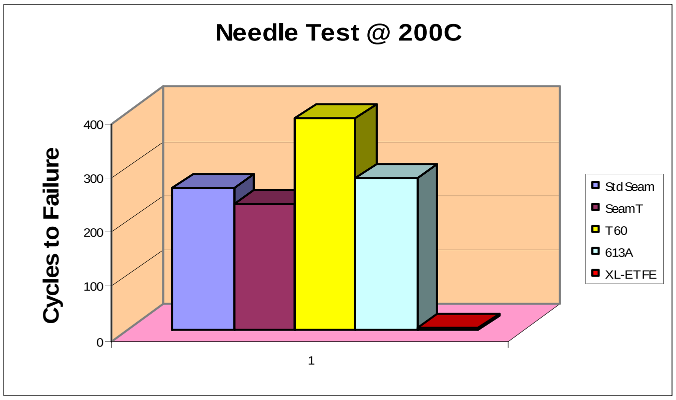

Figure XIIIa. Needle Results at 200°C

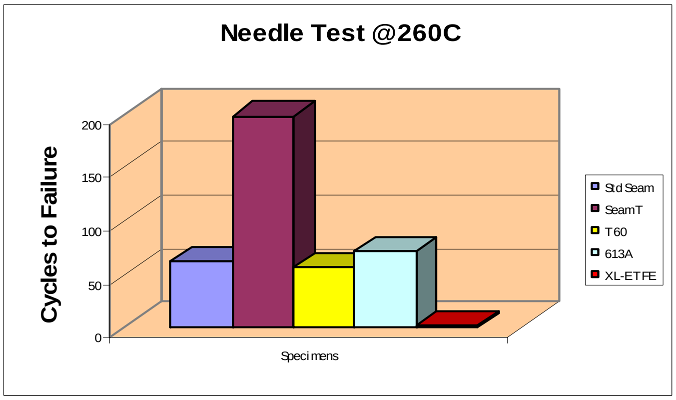

Figure IVXa. Needle Results at 260°C

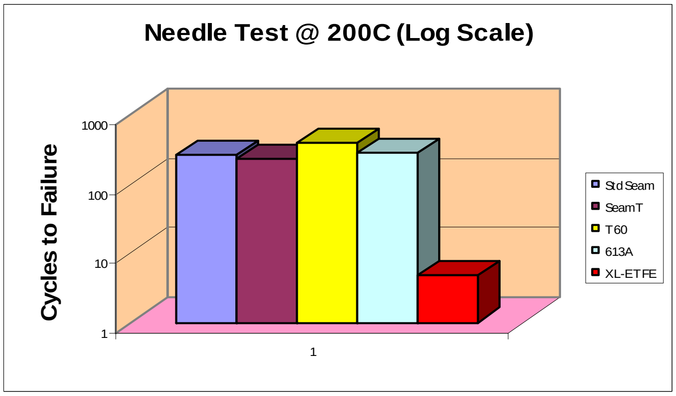

Figure XIIIb. 200°C (Log Scale)

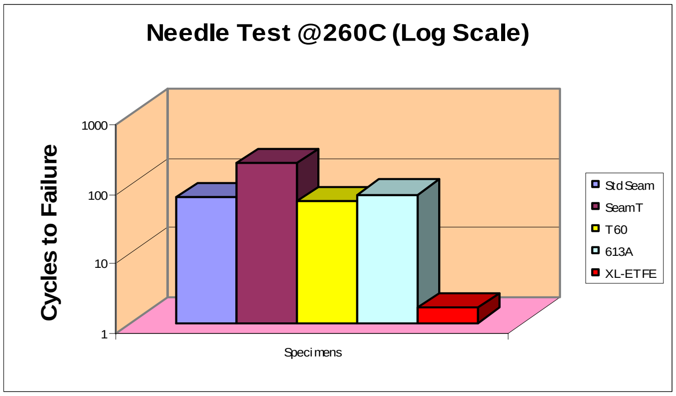

Figure IVXb. 260°C (Log Scale)

	Needle (260C, 5.0 N)				
	Std Seam	**Seam T**	**XL-ETFE**	**T60**	**613A**
1	66	161	2	35	79
2	74	217	1	23	91
3	57	269	2	19	60
4	53	248	2	66	68
5	56	120	2	82	116
6	65	360	2	119	56
7	56	102	1	38	47
8	71	235	2	56	64
9	68	64	1	78	76
10	55	198	1	39	49
AVG	62	197	2	56	71
MIN	53	64	1	19	47
MAX	74	360	2	119	116
MEAN	61	208	2	48	66

Table IX. Needle Abrasion Results at 260°C

The dynamics of the needle abrasion test tends to replicate a compressive environment. The abrading surface (needle) is pushed into the surface by the load (5.0N) and the insulating material tends to migrate away from the force being applied. In this respect, the needle test is a material hardness test.

The compressive load tends to create deformation of the surface area under test and the oscillation of the needle as it is driven by the cam shaft changes the angle of incidence which creates a constantly changing force vector. In the case of softer materials such as PTFE, the material moves to the side of the wire allowing faster initial penetration. The Oasis film, being a much harder material, tends to resist the needle and eventually separates at the adhesive/adhesive junction of the film overlap allowing the polyimide layer to move away from the needle.

Given the dynamics of the test, where the PTFE layer is penetrated rather quickly, well sintered and bonded constructions should perform in a similar manner. The European test community has said for years that all composite constructions with well sintered materials perform in a similar manner.

This fact is also reinforced in this test program. The only temperature where any one product stands out over the other composite constructions is at 260°C, where the improved ***Seamless-T*** construction survives three to four times as many cycles as the other three PTFE constructions. In the three other temperature profiles, the four PTFE candidates provided a rather tight performance gradient of less than 50% differential. Since the natural distribution of results for abrasion testing tend to be rather wide, differential performance of less than 200% is not significant and the materials are considered equivalent. Abrasion results between 200% to 400% can be considered meaningful and greater than 400% are considered significant. In the case of the needle test, the four composite constructions can be considered statistically equivalent.

Conclusion

This paper examined how M22759/41-20 (cross-linked ETFE) and four M22759/87-20 (Normal weight, PTFE/polyimide) insulated wires performed in two separate types of abrasion testing under four temperature profiles. This testing was performed to establish the comparative abrasion characteristics of each wire type and to determine which wire construction offered the most robust performance over the temperature spectrum that the interconnect system would see in an aircraft application.

Both test methodologies confirmed that the M22759/87-20 wire construction, regardless of the PTFE material chosen, demonstrated superior abrasion performance at all temperature profiles compared to the performance of the M22759/41-20. When tested under ambient conditions, the wire insulations wore away from the wire, creating a fine powder residue. This is similar to the findings in aircraft which have experienced this type of chaffing phenomenon.

When examining the performance results of the four different M22759/87-20 PTFE/polyimide constructions, the wire to conductor test identified significant performance differentials between the various PTFE formulations. The primary advantage of this approach is that the tension/stress applied to the surface under test is uniform and does not result in deformation of the wire surface. Also, the insulation tends to ablate versus tearing or migrating away from the abrasion surface which more realistically emulates vibration wear in an airframe. The original Thermax manufactured ***Seamless*** PTFE performed in a similar manner to the non-seamless T60 and 613A tapes currently used in the industry. The new toughened PTFE formulation developed by Thermax and designated as ***Seamless-T***, demonstrated a significant improvement in abrasion resistance. This differential approached an order of magnitude under some test conditions.

The results of the Needle abrasion test confirmed previous studies in that all well sintered PTFE/polyimide wire constructions perform in a similar manner. The needle test is a compressive load wear test where the mechanical and bond strengths of the Oasis film tend to dominate the results and the PTFE layer contributes very little in the overall cycles to failure. This test does provide consistent results and can be used to identify poorly sintered products.

Based on the results of this study, both of these test methodologies would be good candidate methods for product qualification and quality conformance testing. If abrasion is a concern to the end user, reasonable minimum average performance criteria is identified in Table X which could be used to establish performance standards for the product. Also, the Thermax test methods are included in Appendix A and Appendix B. for inclusion in the product specification.

	Minimum Average Cycles to Failure	
Temperature	**Wire-Cond**	**Needle**
23ºC	2,500,000	8,000
150ºC	700,000	1,000
200ºC	200,000	200
260ºC	60,000	100

Table X. Proposed Specification Requirements

Appendix A. Wire to Conductor Abrasion Test

This test method is designed to evaluate an insulated wire's resistance to metallic abrasion in a high vibration environment under various loads and temperatures.

Test Specimens:

Wire A: 20 gauge insulated wire, 24 ± 0.5 inches

Wire B: 20 awg. (19/32) nickel plated copper (NPC) conductor (ASTM-B355), 12 ± 0.25 inches

Method: The test requires a wire and a NPC conductor to be mounted in an oscillating fixture which is enclosed to maintain the required test temperature as prescribed below. The insulated wire specimen (Wire A), with a length of 24 inches, is mounted to the oscillating fixture at one end and the other end is routed over a pulley with a prescribed weight attached. A 20 gauge NPC conductor (ASTM-B355), with a length of 12 inches, is attached to the fixture at both ends in the Wire B position. The relative displacement between the oscillating plates is 0.25 ± 0.01 inches and the oscillating frequency is 10 cycles per second. Wire A and Wire B are connected to detection circuit which stops the counter when continuity is detected between the insulated wire's conductor and the NPC conductor. The insulation wear occurs at the point where the insulated wire and conductor are twisted around each other with the weight attached to insulated wire providing the compressive force to initiate the degradation. A sketch of the required fixture is shown in Figure 1.

Install Wire B (NPC Conductor) to the termination block on the oscillating plane of the test fixture. Terminate one end of the insulated wire specimen (Wire A) to the fixed plane, wrap the wire underneath the NPC conductor (Wire B), over the pulley and terminate with a 5.0 ± 0.25 pound weight. Verify ambient temperature of 23ºC ± 5ºC. Begin the oscillation and allow the test to continue until continuity is detected between the insulated wire's conductor and the metal braid. Record the number of cycles required for penetration. Repeat the test for a total of twelve specimens. Loads of 2.5 ± 0.25 pounds and 9.0 ± 0.25 pounds can also be used to establish additional stress curves. A photograph of the test fixture at ambient is shown in Photo1 and the test fixture at elevated temperatures is shown in Photo 2. Photo 3 depicts a typical extruded product at failure.

Apply a heat source to the enclosure and using thermocouples, verify the temperature of 150ºC ± 5ºC in the enclosure. Allow the enclosure to stabilize for 5 minutes at the prescribed temperature prior to starting the test. Test twelve specimens at a 5.0 pound load. Loads of 2.5 ± 0.25 pounds and 9.0 ± 0.25 pounds can also be used to establish additional stress curves. Once stabilized, begin the oscillation and allow the test to continue until continuity is detected between the insulated wire's conductor and the metal braid. Repeat the test procedure for 200ºC ± 5ºC and 260ºC ± 5ºC respectively.

Results: The highest and lowest reading should be discarded and results of the remaining ten readings evaluated under each weight and temperature condition should be averaged to verify compliance to the minimum specification requirement.

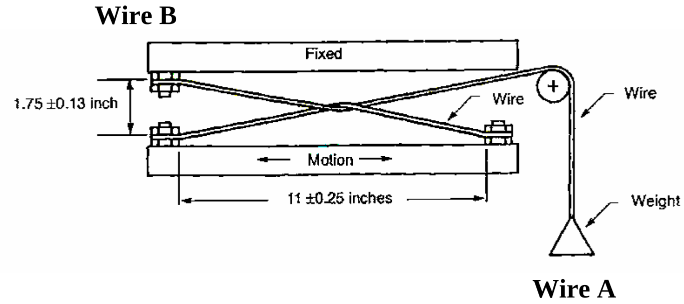

Figure 1. Test Fixture

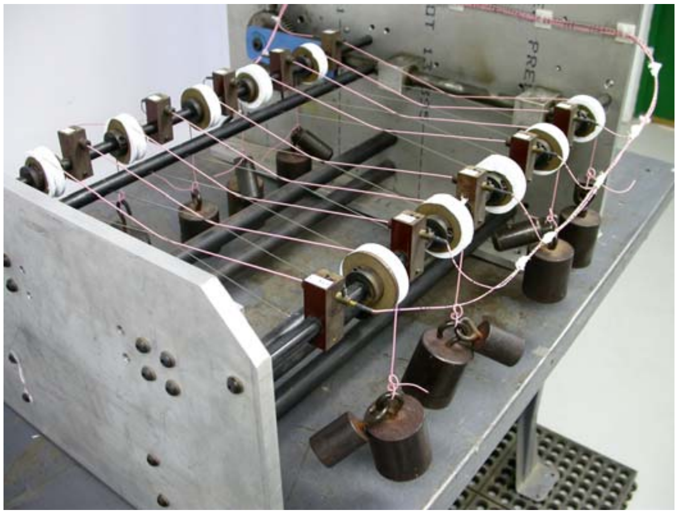

Photo 1. Test Fixture at Ambient

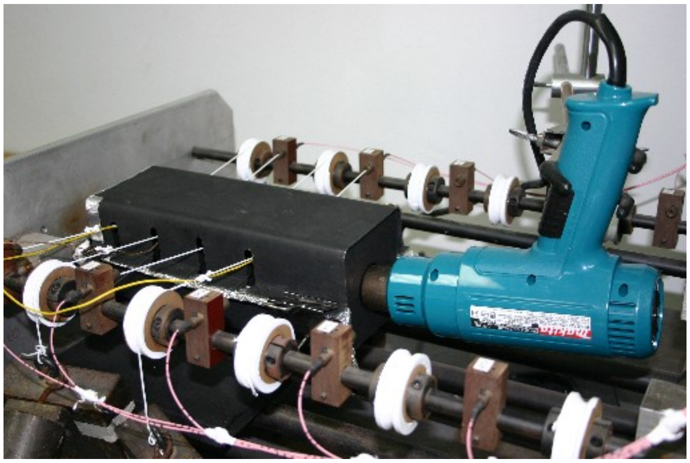

Photo 2. Test Fixture at Elevated Temperatures

Photo 3. Specimen at Failure

Appendix B. Needle Abrasion Test

This test method is designed to evaluate an insulated wire's resistance to cyclic abrasion under various temperatures.

Test Specimen: 20 gauge insulated wire, minimum 6.0 inches

Method: The abrasion durability test fixture shall be designed to hold a 6 inch minimum (152 mm) specimen of finished wire firmly clamped in a horizontal position with the upper longitudinal surface of the specimen fully exposed. The durability apparatus, such as the GE Scrape Abrader Apparatus or equivalent, shall be capable of rubbing a small round dowel with a diameter of approximately 0.020 inches in diameter, repeatedly over the upper surface of the wire. The longitudinal axis of the needle and the specimen must be at right angles to each other. A weight affixed to a jig above the sewing needle shall control the weight normal to the surface of the insulation. A motor-driven, reciprocating cam mechanism and counter shall be used to deliver an accurate number of abrading strokes in a direction parallel to the axis of the specimen. The length of the stroke shall be 3/8 in (9.5 mm) and the frequency of the stroke shall be 120 strokes (60 stroking cycles) per minute. A sketch of the required fixture is shown in Figure I and the geometry of the abrading needle is shown in Figure II. A photograph of a typical test fixture is displayed in Photo I.

Install the wire specimen into the test fixture and apply a 5.0 N load. Strip one end of the test specimen and attached to the circuit detection device. Verify ambient temperature of 23ºC ± 5ºC. Begin the oscillation and allow the test to continue until continuity is detected between the insulated wire's conductor and the abrading rod. Record the number of cycles required for penetration. Repeat the test for a total of twelve specimens. Apply a heat source to the enclosure and using thermocouples, verify the temperature of 150ºC ± 5ºC in the enclosure. Allow the enclosure to stabilize for 5 minutes at the prescribed temperature prior to starting the test. Once stabilized, begin the oscillation and allow the test to continue until continuity is detected between the insulated wire's conductor and the abrading rod. Repeat the test for a total of twelve specimens. Repeat the test procedure for 200ºC ± 5ºC and 260ºC ± 5ºC respectively.

Results: The highest and lowest reading should be discarded at each condition and the remaining ten readings should be averaged to verify compliance with the minimum specification requirement.

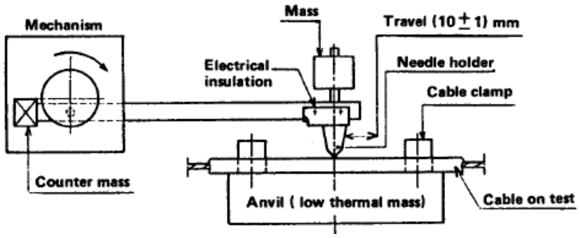

Figure I. Test Fixture

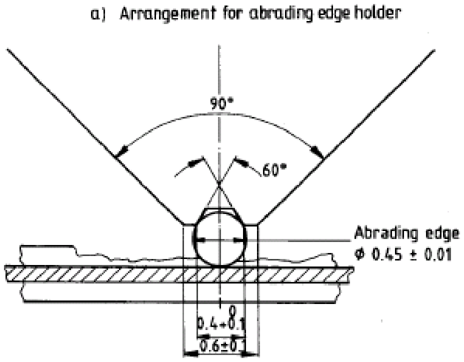

Figure II. Abrading Needle Geometry

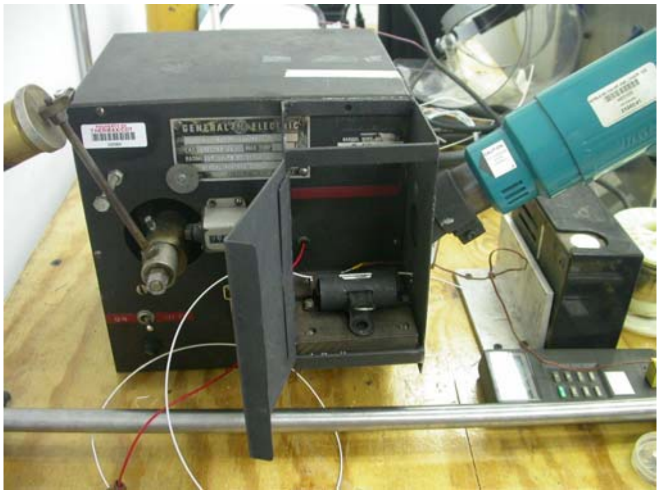

Photo I. Modified Test Fixture