The Performance of Voltage Rated Gloves in Arc Flash Exposures

Background.

Ever since NFPA 70E -2000 was published many customers came to us with a question "How will your gloves perform in arc flash?" From the eyewitness accounts we heard that insulating rubber gloves with leather protectors provide excellent protection from devastating effects of arc flash, but we could not assign a value to the protection level. One should not forget that the primary purpose of the gloves is shock protection.

Currently there is no standard that has a testing procedure that can be used for this test. We had to start from ground zero.
In 2002 we tested the first batch of samples using ASTM F1959-1999 Standard Test Method for Determining the Arc Thermal Performance Value of Materials for Clothing (Fig 1).

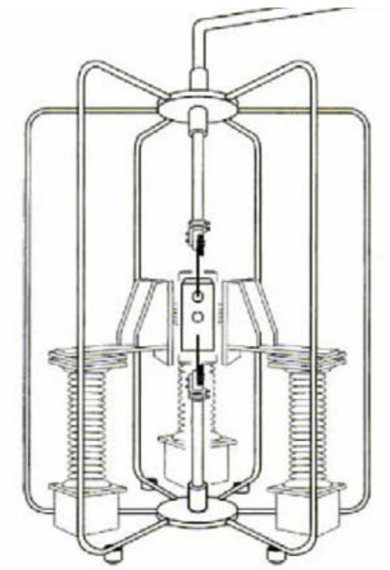

Fig. 1

We have prepared a number of sheet rubber samples that represented different classes of insulating rubber gloves. Also all available colors that are used in manufacturing of rubber gloves were used. Testing was performed by Kinectrics High Current Laboratory. Due to the exposed edges of rubber on the test pane results could not be collated to the finished product that is manufactured by dipping porcelain forms into liquefied rubber solution.

The second and following tests by Salisbury were performed on rubber gloves and leather protectors. This time we used the same test, with a modified panel to allow for full glove testing for both ignition and burn prediction.
During the test the modified version of ASTM F1958 with hands extended and a monitor sensor placed near the center of the chest to measure energy between the two arms. These methods are non-standard but the test parameters were the similar to current standards except for mounting and sensor array configuration changes to allow for glove placement and energy measurement. The gloves orientation was the worst case for ignition but the best for predicting burns.

Test Samples:

Sample Number	Salisbury Product Number	ASTM Class	Maximum Use Voltage a-c rms, V	Sample Thickness (mm)	ASTM Type*	Glove Color
1	E011Y	0	1,000	0.9	I	Yellow
2	E011R	0	1,000	1.0	I	Red
3	E011B	0	1,000	0.85	I	Black
4	E011BL	0	1,000	0.9	II	Blue
5	E0011BL	00	500	0.5	II	Blue
6	E0011BL	00	500	0.7	II	Blue
7	E0011B	00	500	0.7	I	Black
8	E214RB	2	17,000	1.9	I	Red/Black
9	E214B	2	17,000	2.05	I	Black
10	ILPG10	N/A	N/A	1.1	N/A	Goat Leather Protector Used w/class 0 and 00 gloves
11	ILP10	N/A	N/A	1.1	N/A	Cow Leather Protector Used W/Class 0 and 00 Gloves
12	ILP3S	N/A	N/A	1.3	N/A	Cow Leather Protector Used With Class 1-4 Rubber Gloves
13	E214B w/ ILP3S	2	17,000		I	Black Rubber Glove W/Leather Protector

*ASTM D120- designates two types of rubber to be used in manufacturing of rubber gloves Type I – Non Ozone Resistant and Type II – Ozone resistant

The Kinectrics High Current Laboratory uses a 100 MVA supply (100 million volt-amperes). This supply feeds, through co-axial circuit, the current to the arc electrodes which are enclosed by a modified Faraday “cage” to minimize the effects of magnetic fields on the directionality of the arc. The test apparatus is enclosed in a test cell to minimize or eliminate the effect of rain, wind and temperature. . The fault current, the duration of the arc, the arc length, and the test specimen distance from the arc set for each test. The current offset is controlled by point on wave switching of the 60 Hz supply controlled within 0.01 cycles. Monitor sensors on each side of the panels measure the incident energy (E_i) for the panel. Two other sensors are on each panel to measure the pass through energy which is used to model with the Stoll burn criteria predicting second degree burn from the standard.

Instrumented Monitor Sensors: The panels have two copper calorimeters mounted as shown in Figure 2. The monitor sensors each consist of one copper calorimeter and mounting hardware in the center of two glove holders designed to hold size 10 gloves taunt on the holder with only a small amount of FR material for stuffing. For ignition tests we covered the sensors under the gloves when glove ignition was expected.

Test Results: The test program consisted of a minimum of 7 arc tests of three panels (with two gloves) each.
All materials were given Arc Rating as per ASTM F1959 method. Ignition or breakdown levels are recorded in Table 1.

E011Y Class 0 Rubber Gloves (Yellow)	0.9	10.9 (45.6)	31.2 (130.6)	
E011R Class 0 Rubber Gloves (Red)	1.0	7.0 (29.3)	30.6 (128.0)	
E011B Class 0 Rubber Gloves (Black)	0.85	38.4 (160.7)	52.5 (219.7)	
E011BL Class 0 Rubber Gloves (Blue)	0.9	14.9 (62.4)	41.9 (175.4)	
E0011BL Class 00 Rubber Gloves (Blue)	0.5	7.7 (32.3)	17.4 (72.8)	
E0011BL Class 00, Rubber Gloves (Blue)	0.7	11.9 (49.8)	31.2 (130.6)	
E0011B Class 00 Rubber Gloves (Black)	0.7	25.0 (104.6)	31.0 (129.7)	
ILPG10 Low Voltage Goat Leather Protector	1.1	30.0 (125.6)	45.2 (189.2)	
ILP10 Low Voltage Cow Leather Protector	1.1	27.1 (113.4)	43.2 (180.8)	
ILP-3S High Voltage Cow Leather Protector	1.3		35.1 (146.9)	The non-FR PVC on thermoplastic portion ignited. No Stoll burn recorded. The cuff and strap ignited before there was burn predicted (For this reason, we removed the adjuster.
E214RB Class 2 Rubber Gloves (Red/Black)	1.9		34.6 (144.8)	No burn recorded until after ignition.
E214B Class 2 Rubber Gloves (Black)	2.05		93.4 (390.9)	No burn recorded until after ignition.

Table 1

Correlation Study:

The purpose of the correlation study was to determine if the glove ignition probabilities differed with glove orientation. We chose the back vertical orientation for the subsequent studies to give a worst case exposure to the greatest amount of glove area and to allow for sensor location on a relatively flat glove surface (the back of the hand) [See Upright Method above]. To correlate the ignitions using this method, we performed another ignition study on 2 mm thick; E214B Class 2 Rubber Gloves (Black) w/ ILP-3S Leather Protector with nylon adjuster removed and exposed 5 pairs in two orientations pointed toward the arc (Figure 3). This is to simulate a more normal working orientation of glove exposure. In the test set up shown in Figure 3 we measured the closest point of gloves to the arc on each exposure and the range was an average of 7 and 9 inches respectively, depending on the rotation of the glove. Additionally the farthest point, the rubber glove's cuff was 16 inches to the arc and the farthest point of the leather protector's cuff was 12 inches to the arc. The monitor sensor was located at 18 inches from the arc and perpendicular to it.

We exposed 5 pairs of gloves in the configuration shown below to electric arcs ranging from 44.1 cal/cm² to 90.2 cal/cm² at 18 inches away which correlates to the values in the following tables by extrapolation to 16 inches using the square of the distance.

Table 2

Test #	E_i cal/cm² 18 Inches (Sensor)	E_i cal/cm² 16 inches (Rubber glove Cuff)	E_i cal/cm² 9 inches (Side of Hand)	E_i cal/cm² 7 inches (Thumb)
1469	50	63	199	329
	50	63	199	329
	44	56	176	292
	44	56	176	292
1470	77	98	309	511
	77	98	309	511
	63	79	251	415
	63	79	251	415
1471	72	91	287	474
	72	91	287	474
	64	80	254	420
	64	80	254	420
1472	87	110	347	574
	87	110	347	574
	73	92	292	482
	73	92	292	482
1473	90	114	361	596
	90	114	361	596
	85	108	341	564
	85	108	341	564

Conclusion: The "hands-extended configuration" correlates well with the upright method for the rubber glove ignition. Using the Upright Method, the 50% probability of ignition is roughly equivalent to the 10% probability of ignition for the Hands-Extended Method. One could add a safety margin to the Upright Method and to further reduce the probability of ignition if the rubber gloves were used with leather protectors.

	Hands-Extended Method	Upright Method	
Probability of Ignition	Class 2 Rubber Glove Black w/High Voltage Leather Protector	Class 2 Rubber Glove Black	High Voltage Leather Protector Cuff
1%	83	38.1	30.0
5%	89	58.0	31.9
10%	**92**	67.0	32.7
20%	94	76.7	33.6
30%	96	83.2	34.2
40%	98	88.5	34.7
50%	**99**	**93.4**	**35.1**
60%	100	98.3	35.6
70%	102	103.6	36.1
80%	104	110.1	36.7
90%	107	119.9	37.6
95%	109	128.9	38.4
99%	115	148.8	40.2

The Hands-Extended Method is much less harsh on the cuff of the leather protector than the Upright Method. Note in the table above there was relatively no risk of ignitions of the cuff of the leather protector below 83 cal/cm² when using the correlative method.

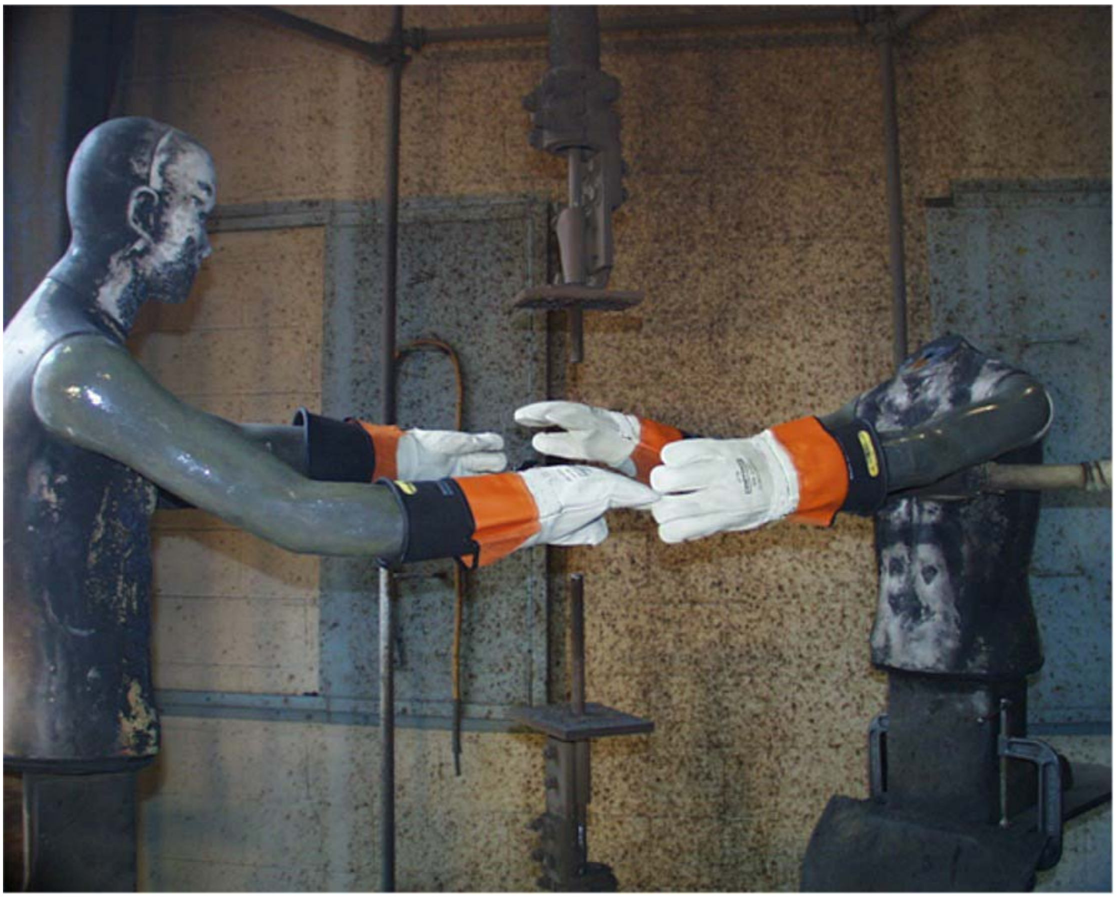

Figure 3 Hands-Extended Method Used

2 mm thick E214B Class 2 Rubber Gloves (Black) w/ ILP-3S Leather Protector with nylon adjuster removed
The testing indicates that the color of the glove makes a difference when it comes to thermal protection from arc events. Yellow and red gloves performed the worst and black gloves performed the best in providing protection from both the onset of a second-degree burn and the probability of ignition of the glove

Bias

ASTM D120 Standard Specification for Rubber Insulating Gloves allows variation in the glove thickness. The tested thicknesses were near the middle of the allowable ranges. Thickness of a glove could play a role in the ignition probability and Stoll performance of a glove as seems apparent in the 0.5 mm and 0.7 mm Type II Blue Class 00 glove's ignition probabilities.

Class of Glove	Minimum Thickness		Maximum Thickness
	In Crotch	Other Than Crotch	
	mm	mm	mm
00	0.20	0.25	0.75
0	0.46	0.51	1.02
1	0.63	0.76	1.52
2	1.02	1.27	2.29
3	1.52	1.90	2.92
4	2.03	2.54	3.56

Different brands could also differ in ignitability since rubber gloves can have diverse component mixtures to meet the minimum specifications for dielectric properties and yet deliver a difference in “feel” and performance.

Obviously, removing the nylon strap from the High Voltage Leather Protectors biased the results but this strap burned so badly and at a low exposure that we could not have performed useful research for the purpose of determining the protective capabilities of the system. The nylon strap might not cause injury in many cases since the strap has a full thickness of leather and rubber glove between it and the wearer but the nylon strap could melt and run in some situations thus the mention of it in the bias.