ARC-RATED CLOTHING

Evaluation of the Effects of Sweat & Layering on Performance

By Stacy L. Klausing and Hugh Hoagland

BEFORE AN INDUSTRIAL FLAME-RESISTANT (FR), arc-rated (AR) product goes to market, rigorous large-scale arc flash testing occurs to determine whether the product is compliant. In the case of arc flash protective clothing, compliance is determined through both small-scale methods (e.g., vertical flame testing to ASTM D6413 as well as physical tests for strength, colorfastness and dimensional change) and large-scale arc flash testing (ASTM F1959, 2014). The output of arc flash testing is a rating, or a protection value, reported in kW/m² [cal/cm²]. This rating, when tested to ASTM F1959 per ASTM F1506, is then only assigned to materials that do not ignite and continue to burn for longer than 5 seconds, and that show no propensity for melting and dripping (ASTM F1506, 2017); these are the criteria required to pass the test for a material to be assigned with an arc rating for use in industry. Testing to ASTM F1959 is performed after three wash cycles and one drying cycle. These attributes in a material are important in FR clothing, as clothing ignition increases body burn, and melting and dripping in testing indicate that in a field exposure a material would melt and drip, causing significant burn injury (Choudhury, 2017).

OSHA 1910.269, which covers operation and maintenance of electric power generation, control, transformation, transmission, and distribution lines and equipment, requires employers to outfit employees in garments that match the hazard of exposure (per OSHA requirements, employers are required to assess workplaces to determine whether hazards are present and to identify them). In the instance of AR clothing, the large-scale arc testing is used to categorize fabrics, composites and products with a specific protection level; this protection level is deemed the arc rating through appropriate testing, and it is the value used to “match the hazard.”

In the U.S., the market and, to an extent, OSHA regulate the voluntary consensus standards used for compliance. These industry-accepted specifications are used in research and development, and manufacturing to determine compliance; the final manufactured material must demonstrate that it meets minimum industry requirements in laboratory testing.

What happens after the purchase when the garment is put to the test in the field? Laboratory testing has limitations in that it is intended to balance real-life scenarios with repeatability to fairly compare products. What variables are present in the field, not present in testing, that could affect the arc rating and protection values? For example, how do variables such as the addition of moisture and contamination in clothing affect protection?

Safety directors and users have long questioned the effects of sweat on the functionality of PPE. Considerations of moisture in clothing and heat illness can be a priority among those designing PPE programs for companies and employees. Sweat is a concern for those with electrical and flash fire hazards, as many users question the effect of moisture on the protective properties of the materials in relation to heat transfer. A previous study using a bench-scale flame test with FR materials used for wildland firefighting found that at a flame exposure with a heat flux of 83 kW/m², external moisture tended to decrease heat transfer and internal moisture tended to increase heat transfer (Lawson, Crown, Ackerman, et al., 2004). Steam burns are also a concern for users when moisture is present in clothing. Arc flash testing is performed at high incident energy levels, so the addition of moisture both externally and internally is

KEY TAKEAWAYS

- **The effects of sweat and layering clothing in field use of arc-rated garments has been questioned with little research.**
- **This study aimed to formulate a conclusion on the effects of sweat and the impact of layering materials by compiling previous work and continuing to evaluate the effects of moisture on protection values of arc-rated materials using testing to the ASTM F1959 standard.**
- **This article explores how moisture affects the protection level of clothing or PPE when faced with arc flash, examines the effects for single- versus double-layer systems, and seeks to determine whether a worker is better off wearing arc-resistant rainwear rather than getting wet in the rain.**

FIGURE 1
ARC RATING OF ORANGE 88/12 MATERIAL (CAL/CM²)

Decreased arc rating with addition of moisture in 7 oz. orange 88/12 cotton/nylon material.

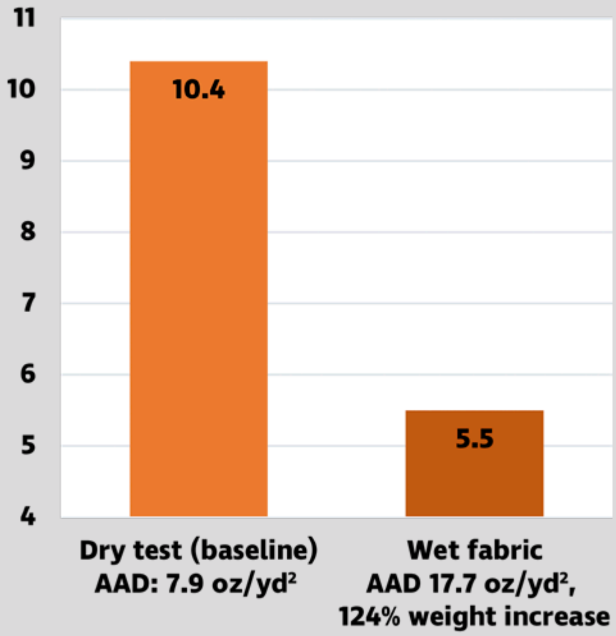
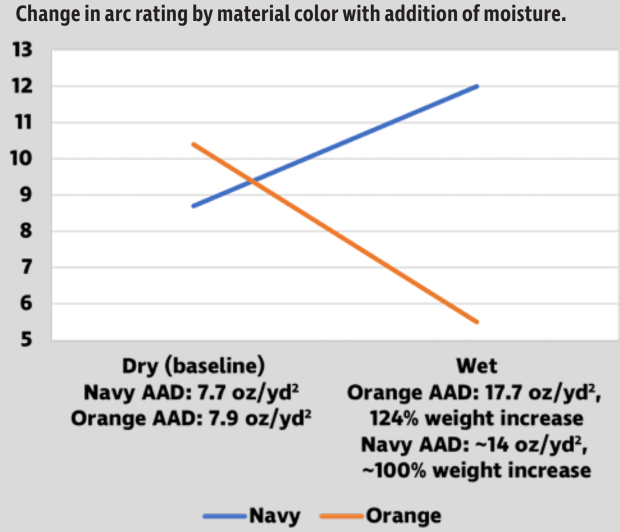


FIGURE 2
CHANGE IN RATING WITH MOISTURE (CAL/CM²)

Change in arc rating by material color with addition of moisture.



of interest. In addition, heat stress of the worker is also a concern, as it affects roughly 2,600 workers per year (OSHA, 2019). Finding the balance between keeping workers comfortable and protected, including while in the elements, is important in any successful PPE program.

Comfort contributes to worker effectiveness and can sometimes be the primary deciding factor for a worker choosing to wear FR/AR clothing at all. In the case of rainwear, some workers choose not to don the garments because they can increase heat stress and sweating, making the daily wear underneath feel wet. If the rainwear is breathable and provides proper fit and venting, wearer comfort is achievable.

Ensuring that industrial workers are wearing FR/AR clothing reduces risk of ignition and burn injury. An American Burn Association study found that there is a greater than 90% chance of survival of all age groups if body burns are kept below 25% (Saffle, Davis & Williams, 1995). Such low body burn predictions can only be achieved if clothing does not ignite with continued combustion and the selected AR materials provide protection for the anticipated arc hazard.

In this study, the authors evaluate the protection levels provided by rainwear with the inclusion of moisture. This article explores common questions regarding field use from users, manufacturers and safety directors designing PPE programs:

1) How does moisture affect the protection level of clothing when faced with an arc flash?

2) Are the effects different in single- versus double-layer systems?

3) Is a worker better off wearing arc-resistant rainwear rather than getting wet in the rain?

This article includes a compilation of substudies performed by ArcWear between 2012 and 2017 to draw broad conclusions on the effects of moisture on various types of AR materials and composites. All fabrics and fabric combinations were evaluated in accordance with ASTM F1959, Standard Test Method for Determining the Arc Rating of Materials for Clothing (ASTM, 2014). In all studies, the contaminant used was 1% by mass saline solution. This is a large-scale test performed in a laboratory setting with a fixed current and voltage; variable durations are used to increase the incident energy to the fabric. A minimum of 20 data points are obtained for each test and a logistic regression is performed to provide the result: an arc rating. The arc rating may be expressed as either an arc thermal performance value (ATPV, 50% probability of crossing the Stoll curve, a theoretical skin burn injury model) or an energy breakopen threshold (EBT) value (50% probability of a 0.5-in.² breakopen in the material). In terms of protection levels, the two different rating types are functional equivalents; the ATPV result is a probability of the wearer experiencing a second-degree burn, and an EBT value implies the point where a small area of skin exposure may occur. Both are conservative protection thresholds at the described energy level. All tests were performed after three wash cycles in accordance with American Association of Textile Chemists and Colorists (AATCC) test method 135; parameters 3 (permanent press), IV (120 ±5 °F), Aiii (tumble dry permanent press), as cited by the ASTM F1959 standard. Average areal density (AAD), or the post-laundered fabric weight, was measured and is reported with results.

In few cases, a partial rating was obtained (fewer than 20 data points) to estimate an arc rating. Such cases are noted with the population of data points used for analysis. Various moisture levels were used in each substudy as identified; sweat loss in humans can exceed 1.5 L per hour (Bates & Miller, 2008).

Sweat & Daily Wear
88/12 Cotton/Nylon Material

Individuals with exposure to flash fires and electric arcs should use daily-wear clothing that serves to minimize injury if an incident should occur. To begin evaluating the effects of moisture on AR materials, especially in daily wear, a commonly used single-layer fabric blend was chosen for testing. The 88/12 cotton/nylon blend is prevalent on the market because it is comfortable to wearers and relatively inexpensive. This blend was also used as the base layer in multilayer projects discussed later in this article.

In an initial contamination study performed by Hoagland, Smith, Golovkov, et al. (2012), an 88/12 cotton/nylon, 7.0 oz/yd², AAD or post-laundered weight of 7.9 oz/yd², orange fabric was arc rated to ASTM F1959 as a single layer both before and after application of a sweat simulated saline solution. The material was saturated with 1% by mass saline solution (average weight of panels after application of saline was 17.7 oz/yd², 124% increase). The baseline arc rating obtained on this material was an ATPV of 10.4 cal/cm² and the arc rating obtained after fabric saturation with the saline solution was an ATPV of 5.5 cal/cm², a 47% decrease in arc rating (Figure 1).

In another substudy performed in November 2015, a navy blue, 7 oz/yd² 88/12 cotton/nylon material used monthly as a control material in arc testing was also tested wet. The weight measurement of the material was not documented, but internal procedure notated in testing was to add moisture of an approximate 100% weight gain (post-laundered, wet weight of material was approximately 14 oz/yd²). The findings of this arc rating contrasted with the study performed on the same material tested in orange: the result increased from an average baseline arc rating of 8.7 to 12 cal/cm² with the addition of moisture. It is possible that the dyes used in this material, combined with moisture, resulted in an increased arc rating. However, the uptake of moisture is unknown in the navy material, and it is possible that the differences in moisture level resulted in an effect on the arc rating.

Figure 2 displays the results of testing before and after the addition of moisture of the orange and navy 88/12 materials. With the addition of moisture, the findings of the two fabrics were contradictory; however, in both cases, there was no increased risk of ignition when moisture was introduced.

Blended Fabrics

A second control fabric was evaluated for effects of moisture in October 2016; the material used was a 6-oz. ripstop 60% Kevlar, 40% polybenzimidazole (PBI) blend. The average arc rating of the material dry was measured in accordance with ASTM F1959 to be 7.2 cal/cm² (averaged from six ratings obtained between August 2016 and February 2017). With the addition of moisture (approximately 100% increase in fabric weight using a 1% saline solution), the arc rating was tested to be 7.4 cal/cm² a slight increase in arc rating (Figure 3). This increase, however, is within the normal variance of the test (approximately 0.5 cal/cm² at 2 sigma based on 3 years of control data) as the increase in rating cannot conclusively be attributed to moisture. However, the fact that both ratings fell within the normal variance of the test may indicate that moisture level had little effect on the arc protection level for this material. No evidence of ignition or afterflame was found in this test.

A 2012 study investigated incremental moisture increases with a 7-oz. cotton, modacrylic and para-aramid blended twill fabric. There was a negative correlation associated with the addition of moisture into the fabric (Figure 4); however, no ignition or afterflame issues were observed in any of the testing performed on the single layer materials.

FIGURE 3
KEVLAR PBI BLENDED FABRIC TESTED WITH MOISTURE

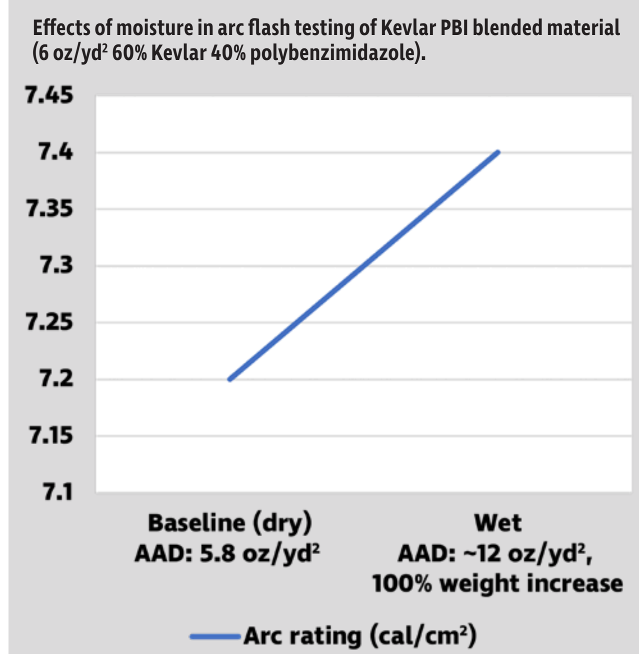
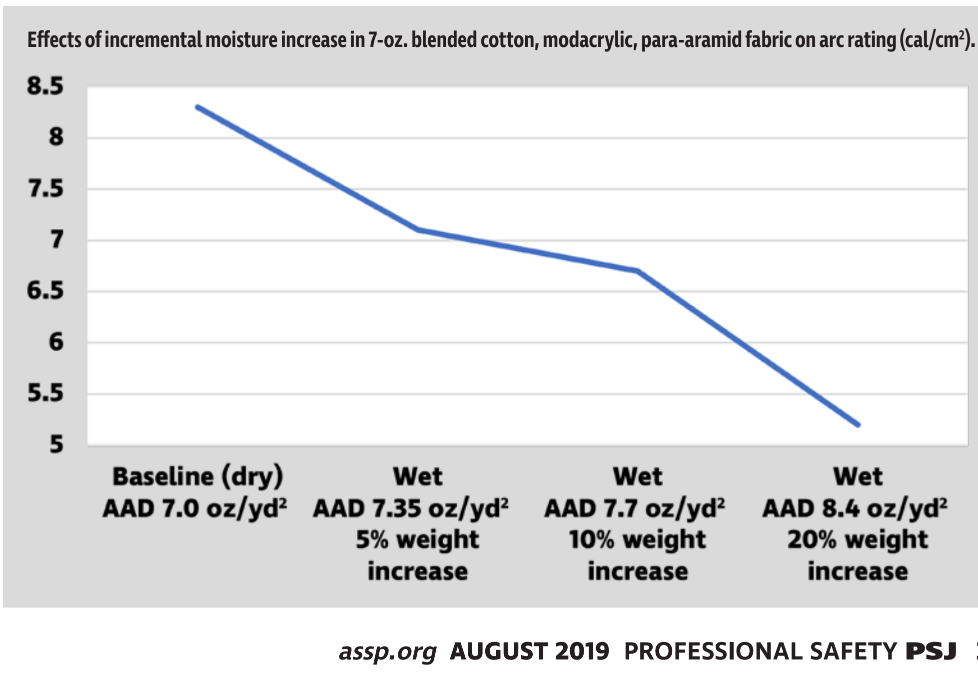


FIGURE 4
EFFECTS ON ARC RATING OF MOISTURE IN BLENDED COTTON, MODACRYLIC, PARA-ARAMID FABRIC



A summary of the wet and dry evaluations of all single layer fabrics studied is shown in Figure 5. The moisture levels used in the substudies varied. As Figure 5 shows, two ratings decreased and one increased. The para-aramid PBI blend evaluated in this study maintained the arc rating with the addition of moisture, which may indicate that this blend is less likely to be affected by the presence of sweat or moisture in the field. The addition of moisture did not introduce or increase the risk of ignition and afterflame of any of the materials evaluated in this study.

Two-Layer Systems

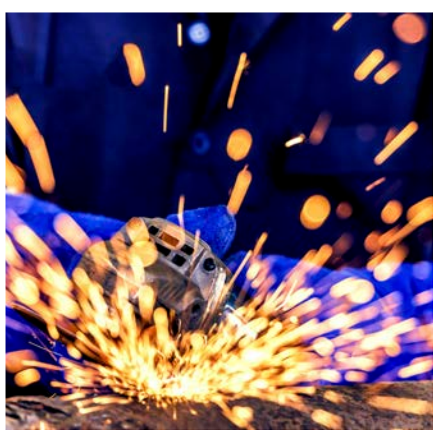
As part of the 2012 substudy, multilayer systems were tested to evaluate the effects of moisture when one or both layers is introduced to moisture or sweat in a two-layer system. Evaluations were performed on each two-layer system to estimate an arc rating.

Evaluations were performed with the following moisture variations using a 1% by mass saline solution:

1) both layers tested dry;
2) both layers tested wet (~30% moisture added to each layer);
3) wet base layer (~30% moisture added) to simulate a sweating worker with a dry outer layer.

The inner and outer layers of the two systems and the results of testing are described in Table 1, and a visual representation is depicted in Figure 6.

This study explored how moisture affects the protection level of arc-rated clothing or PPE.



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As expected in system A, the combinations evaluated with moisture obtained ATPV ratings as opposed to EBT ratings (breakopen). This may be attributed to an increase in speed of heat transfer from the addition of moisture into the textile. There was also a decline in the arc rating as more moisture was added to the system; the lowest rating occurred when both layers were tested wet in system A.

When the base layer was wet with a dry outer layer in system B, there was a slight increase in arc rating; however, the researchers attributed this to normal variability in testing. This system had a heavier outer layer than inner layer, and all three ratings were relatively close together with a range of 2.4 cal/cm².

While the protection level of both two-layer systems level decreased, there was no increased risk of ignition. The results of testing two-layer systems with moisture, including two saturated layers, may indicate that field use PPE containing moisture

FIGURE 5

EFFECTS OF MOISTURE ON ARC RATING: SINGLE LAYER FABRICS (CAL/CM²)

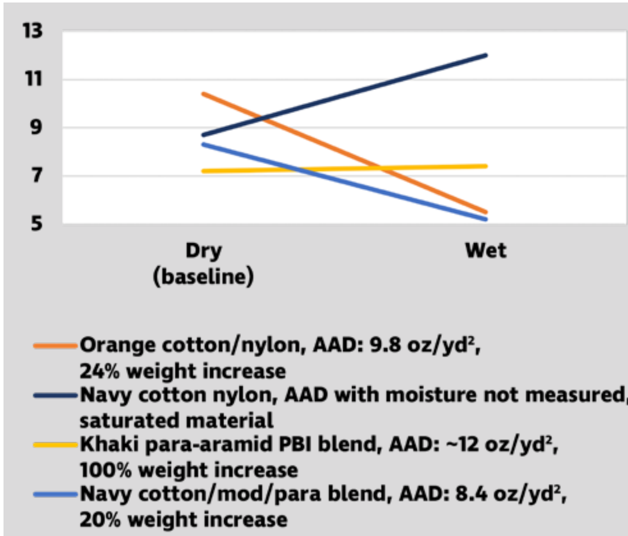


TABLE 1

ARC TESTING RESULTS OF TWO-LAYER SYSTEMS WITH MOISTURE

System ID	Description	Rating: Both layers dry	Rating: Dry over wet	Rating: Both layers wet
A	7.0 oz/yd² 237 g/m² twill, 80% modacrylic, 15% cotton, 5% para-aramid, medium blue over 5.4 oz/yd² 237 g/m² jersey knit, 75% modacrylic, 15% cotton, 10% nylon, coyote, AAD 5.4 oz/yd² 149 g/m²	EBT = 23 cal/cm²	Estimated ATPV ~18.4 cal/cm²	ATPV 12.6 cal/cm²
B	7.0 oz/yd² 237 g/m² woven, 88% cotton 12% nylon, medium blue, AAD 7.9 oz/yd² 268 g/m² over 4.5 oz/yd² 152 g/m² knit, 100% cotton, AAD 4.4 oz/yd² 149 g/m²	ATPV 14.8 cal/cm²	ATPV 15.9 cal/cm²	ATPV 13.5 cal/cm²

(such as rain or sweat) is likely still more protective than non-FR clothing, as no increased risk of ignition was found.

Rainwear

The researchers sought to determine whether worker protection was increased or decreased by the addition of rainwear, as concerns exist in industry regarding the actual protection provided by rainwear if it causes the wearer to sweat excessively through the base layers of clothing underneath. Some workers avoid rainwear as they believe they will be more protected and comfortable in a breathable, noncoated or laminated single layer of clothing alone.

To test the protection levels provided by rainwear when moisture levels are increased underneath due to sweat and humidity, evaluations were performed by ArcWear and W.L. Gore & Associates Inc. using two different commercially available rainwear materials over a wet base material. The rainwear materials consisted of a high-visibility orange semipermeable material or impermeable (PVC-coated meta-aramid) and the base was a 7 oz/yd^2 orange 88/12 cotton/nylon fabric. Orange was chosen for purposes of this study as it has been found through previous research to produce lower arc ratings than darker colors (Hoagland, 2013). Testing was performed dry and at two moisture levels. In the cases where 60 g (100% weight increase) of saline solution was added, a partial test was performed (six data points) and the result was estimated using the algorithm in ASTM F1959 (Table 2).

Previous work with this fabric was performed at a 100% weight added level. This corresponds to a saturated layer, which can be found at high workloads and sweat rates (~1 L/hour). The researchers chose to perform evaluations at higher and lower moisture levels. A lower moisture level (50% added) corresponds to a moderate sweat level—the layer is damp, but not saturated. Wringing the textile did not result in water dripping out of the fabrics, so this moderate level may correspond to more typical sweat rates (≤ 0.5 L/hour).

The test results indicate that when a high amount of moisture was added (100% added weight and total saturation), the arc rating of the system was higher than the baseline dry system; both rainwear materials had a similar performance. At moderate moisture levels (50% added), the rating of one style of rainwear

FIGURE 6
TWO-LAYER SYSTEMS TESTED WITH ADDITION OF MOISTURE

Arc ratings (cal/cm^2) of two-layer system with introduction of moisture: ~30% weight increase to each wet layer.

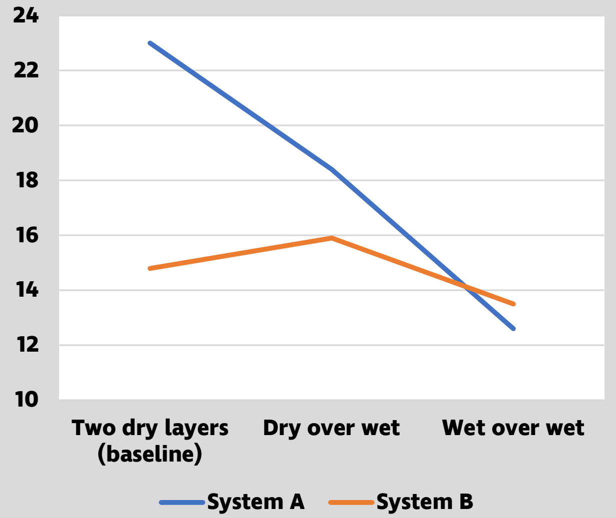
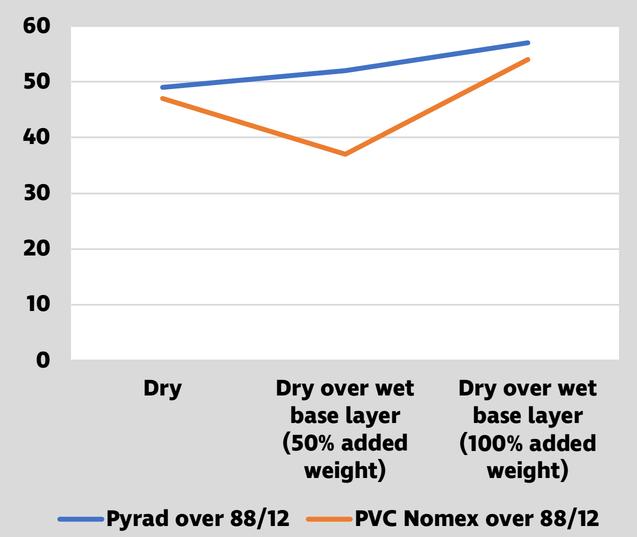


TABLE 2
ARC TESTING RESULTS OF TWO-LAYER RAINWEAR SYSTEMS WITH VARYING MOISTURE CONTENT

Materials	Data points obtained	Test result	Moisture summary
Baseline: Dry hi-vis orange semipermeable rainwear over dry 88/12	21	ATPV 49	Dry
Baseline: Dry PVC-coated meta-aramid over dry 88/12	21	ATPV 47	Dry
Dry hi-vis orange semipermeable rainwear over wet 88/12 (30 g of 1% saline solution)	21	ATPV 52	Wet: 30 g, 50% weight increase
Dry PVC-coated meta-aramid over wet 88/12 (30 g of 1% saline solution)	21	ATPV 37	Wet: 30 g, 50% weight increase
Dry hi-vis orange semipermeable rainwear over wet 88/12 (60 g of 1% saline solution)	6	ATPV ~57	Wet: 60 g, 100% weight increase
Dry PVC-coated meta-aramid over wet 88/12 (60 g of 1% saline solution)	6	ATPV ~54	Wet: 60 g, 100% weight increase

FIGURE 7

COMPARISON OF MATERIALS WITH SAME BASE & ADDITION OF MOISTURE



increased and the other decreased; however, neither showed a propensity to melt and drip or ignited in testing (Figure 7).

The results of testing indicate that rainwear does, in fact, increase protection even if the base-layer worn by the worker is wet. Results indicate that users will have more protection wearing AR rainwear than the alternative of choosing to omit rainwear and wearing wet daily wear. Further, wearing AR rainwear allows for protection at higher energy levels, and also allows users to be sure the rainwear has been tested to the hazard and will not melt and drip in a real-life incident. OSHA 1910.269 specifies that rainwear be flame resistant and does not technically require AR rainwear; however, there are products on the market claiming flame resistance that would not be appropriate in an arc flash hazard.

Conclusion

This study evaluated the protection levels provided by rainwear with the inclusion of moisture, and explored common questions regarding field use:

1) How does moisture affect the protection level of clothing when faced with an arc flash?

In any of the evaluations performed, the risk for ignition did not increase with the addition of moisture. AR clothing, even when wet, is more protective than non-FR clothing, which ignites. In some cases, the arc rating was lowered, but all items tested provided a level of protection even when wet. The addition of rainwear increased protection levels.

2) Are the effects different in single- versus double-layer systems?

No significant differences between single- and double-layer fabrics were observed. While the arc rating decreased with the addition of moisture, the risk of ignition did not increase.

3) Is a worker better off wearing arc-resistant rainwear rather than getting wet in the rain?

Yes, especially when higher protection levels are required. The addition of arc-rated rainwear, even when moisture is present in the garments worn underneath, is more protective than without rainwear and poses no increased risk of ignition or melting and dripping to the wearer. While wearing rainwear can make users feel hot due to the nature of their construction (coated and laminated materials), which is intended to shed rain, finding breathable rainwear with proper fit and venting can make users more comfortable while increasing protection.

Through a compilation of research projects, the authors have found that there is no catch-all when it comes to moisture. The effects must be considered along with the hazard level and the circumstances of use, and the protection level required must be balanced with wearer comfort. The authors' recommendation is for users to always match the hazard and to wear arc-rated rainwear that is breathable and that provides adequate fit and venting to maximize comfort when exposed to the elements. **PSJ**

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Stacy L. Klausing is the PPE project manager at ArcWear, a third-party accredited laboratory for flame, thermal and arc-flash hazards. She has spent more than a decade working with flame-resistant textiles and PPE, and coordinates testing and compliance of electrical arc flash PPE products. She has experience with ISO 17025 quality control systems in laboratories, project management in testing laboratories, standards and compliance, and research and development. She holds an M.S. in Merchandising, Apparel and Textiles from University of Kentucky with a special focus on textile science and flame-resistant textiles.

Hugh Hoagland is a trainer and researcher in electric arc protection. He serves as an expert witness and performs incident investigations. His NFPA 70E and OSHA 1910.269/NESC training programs are used by Fortune 500 companies and governmental agencies including Alcoa, GM, Toyota, Department of Energy and hundreds of electric utilities. Hoagland has performed and developed testing (by original research and participation in numerous standards groups) for electric arc since 1994, and he has performed more than 50,000 electric arc tests. His has many publications in IEEE and safety magazines, and he helped invent many arc-rated materials used today.

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