

Comparing the Flammability of Fabrics in Accordance with EN 531 and ENV 50354

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The purpose of protective clothing and other personal protective equipment (PPE) is to provide escape time, to reduce the burn injury level, and to prevent aggravation of the consequences to workers during exposure to an electric arc. In this study the flammability properties of 12 different types of flame-retardant fabrics were compared with the normally used flame spread test method (EN 532:1994) and electric arc test method (ENV 50354:2001). In the arc test at the lower testing current level of 4 kA, the requirement was passed by materials which did not pass the flame spread test. These materials contained a large amount of melting fibres, and therefore tended to shrink or melt. In order to meet the current level of 7 kA, a rather thick and heavy flame-retardant fabric is needed to pass the requirement. Lighter fabrics tended to break open in the tests. The flame retardancy of the under layer fabric is therefore important to ensure the needed protection.

electric arc protective clothing testing of flammability

1. INTRODUCTION

“A worker’s tool touched a live part and caused a short circuit. The resulting electric arc ignited the worker’s clothing. He got third degree burns on his body”. This is an example of the consequences of one type of electric arc accident. Thermal energy produced by an electric arc is determined by the current, duration of the arc, length of the arc, and distance from the arc [1]. Removing the source of the risk completely and ensuring safe operating practices are the primary preventive measures. The purpose of protective clothing and other personal protective equipment (PPE) is to provide escape time, to reduce burn injury level, and to prevent aggravating the consequences to workers exposed to electric arcs. The measurable characteristics of garment’s

performance that affect the accident situations are ease of ignition, degree and ease of flame spread, heat produced during burning, rate of heat transfer, ease of extinguishing the flame, and melting of the fabric.

In Finland, 65 serious electric arc accidents occurred in 1977–1986, and 14 injured workers died in these accidents [2]. A more detailed accident study was carried out on serious electric arc accidents that occurred in 1996–1999. In this study electric arc accidents ($N = 25$) were investigated in order to obtain information on the risk levels and the role of protective clothing in the accidents. Seventy-two percent of the accidents took place in a low voltage installation, the switching time varied between 0.1 and 1.5 s, and the short circuit current was higher than 10 kA in 7 cases, below in 12 cases, and unknown in 6. Hands

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were the most frequently (71%) injured part of the body. Flame-retardant (FR) protective clothing was worn by 48% of the victims. Accidents that led to bodily injury occurred more often to workers who did not wear FR protective clothing [3].

Those figures show the effect of the requirements for clothing. Since 1986 it has been required in Finland that the clothing used in work involving the risk of an electric arc has to be made of a FR material [4]. The after-flame time of the FR material must be under 10 s, vertical hole length under 150 mm, damaged area under 150 mm, and no molten debris is allowed when the material is tested in accordance with ISO 6941:1984 [5]. Although the requirement level is lower than the flame spread requirement of EN 531:1995 [6], it has apparently cut down the number of serious electric arc accidents, as there were no fatal occupational electric arc accidents among electricians in the 1990s [3]. Of course also the development of electrical equipment and installations, as well as working methods, i.e. the use of reclosers and breakers, have had an effect on this positive trend. The workers have also become more aware of the risks of electricity. Similar experiences have been reported from other countries; the Occupational Safety and Health Administration (OSHA) in the USA issued a rule on the clothing of electrical workers in 1994. This has reduced the severity of burn injuries and has saved lives [7].

The European directive on PPE requires that all PPE, before entering the market and before being taken into use must be type-examined [8]. During type-examination a Notified Body checks whether the PPE meets the basic health and safety requirements of the directive. Harmonized European standards explain the required levels for types of PPE. As yet, there is no harmonised standard which explains the requirements of the PPE directive for materials and garments used in work entailing risk from exposure to an electric

arc. The requirement of EN 531:1995 for flame spread is therefore often applied to protective clothing in the safety requirements of electricians [9]. In addition, the Technical Committee CENELEC/TC78 has prepared a pre-standard test method, ENV 50354:2001 [10], which is currently published as a technical report CLC/TC 50354:2003. This method attempts to create a realistic scenario by producing a specified electric arc. The purpose of the test method is to ensure that the clothing itself will not aggravate the consequences of the exposure to electric arcs. However, this method does not include the measurement of the thermal protection from the heat energy generated by the electric arc. This is included in the more complicated International Electrotechnical Commission (IEC) test method, IEC 61482-1 [11].

The aim of this study was to compare the flammability of different types of FR fabrics with two tests that are commonly used to evaluate the flammability of the fabrics of protective garments worn by electricians whose clothing is at risk of being ignited.

2. MATERIALS AND METHODS

2.1. Materials

We measured the flammability of 12 different types of fabrics (Table 1). The materials were selected on the basis of their suitability for garments intended for outdoor tasks. Electricians prefer materials that repel water and do not get wet easily. Some of the materials were selected because they met the previous flammability requirement and had been widely used by electricians. These materials have also been evaluated to meet the users' needs better than FR cotton in all other respects except flame retardancy. Especially during wet winter weather, FR polyester is perceived to be a more suitable material for outdoor work tasks [12].

TABLE 1. Tested Materials

Fabric No.	Fibre Content	Construction	Mass Per Unit Area (g/m ²)
1	63/37% CO/PES	twill	365
2	52/48% PES/CO	twill	320
3	100% CO, proban	satin	320
4	100% FRPES	twill	230
5	70/30% CO/PES	twill	240
6	50/50% CO/PES	twill	260
7	75/25% CO/PES, proban	twill	310
8	100% CO, proban	twill	175
9	60/40% CO/PES	satin	330
10	75/25% CO/PES, proban	twill	340
11	100% Aramid	plain	165
12	100% Aramid	twill	260

Notes. CO—cotton, PES—polyester FR—flame-retardant.

2.2. Methods

2.2.1. Flame spread test

Flame spread was tested according to EN 532: 1994 [13] and evaluated as required in EN 531: 1995 [6] for code letter A. A flame of 15 mm produced by a propane gas burner is directed for 10 s at the surface of the test fabric at a distance of 17 mm (Figure 1). The temperature of the flame is about 800 °C. The samples must meet the following requirements for code letter A:

- No specimen shall burn to the top or either side;
- Holes shall not be formed;



Figure 1. Flame-spread test.

- No specimen shall melt nor burn or leave molten debris;
- The mean after-flame time shall be ≤ 2 s;
- The mean after-glow time shall be ≤ 2 s.

2.2.2. Electrical arc test

ENV 50354:2001 [10] is based on a fixed test setup and a testing circuit. The electric arc is produced by Cu/Al electrodes with a cap of 30 mm and placed in a test box made of plaster (Figure 2). It is designed to direct the energy of an electric arc to the samples, thus intensifying

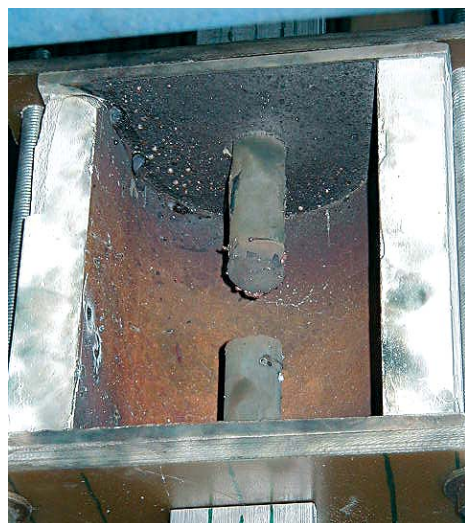


Figure 2. Test box of the arc test.

the effect of the electric arc, so that a lower test current can be used. The electrodes are placed vertically; the upper electrode is aluminium and the lower one copper. The supply voltage is 400 V, and the duration of the electric arc is 0.50 s. The prospective test current is 4 kA in class 1 and 7 kA in class 2. The test conditions are planned to be comparable to accident situations in low-voltage installations and networks [14]. A rough comparison with regard to the test intensity during comparison tests has shown that this method at 7 kA compares quite well with the IEC test method (8 kA/250ms/30cm). In both cases an energy value of approximately 423 kWs/m² can be taken for granted [14].

For material testing, the test plate is $(400 \pm 10) \times (400 \pm 10)$ mm, and for garment testing a test mannequin comprising only an upper body torso with a chest measurement of 1020 ± 20 mm is used. In our test the test plate was fixed on the breast of the upper body torso (Figure 3a). Figure 3b shows the electric arc test at a current of 4 kA.

The tests are video-recorded and the results are evaluated using the following criteria:

- Burning time ≤ 5 s after exposure to the electric arc;
- No melting through of the samples to the inner layers;

- No perforation of the samples with holes of >5 mm (in all directions);
- Maintenance of the function of all accessories in the case of ready-made clothes.

Before testing, all materials were conditioned for at least 24 hrs in an atmosphere with a temperature of 20 ± 2 °C and a relative humidity of $65 \pm 5\%$. The materials for the arc test were taken to the testing site after being conditioned in double-layer plastic bags.

3. RESULTS

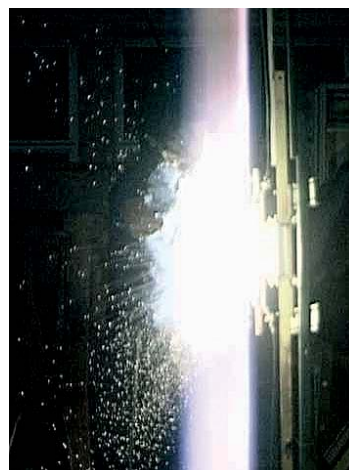
3.1. Flame Spread Testing in Relation to Arc Testing at 4 kA

Fabric 4 of 100% FR polyester melted up to edges, and did not meet the requirements of both standards. Fabrics containing 50% or more polyester, namely fabrics 2 and 6, displayed problems in the flame spread test, whereas in the arc test at 4 kA these fabrics only hardened and shrank a little without hole formation. The fabrics were evaluated to meet the arc test requirement of class 1. Figure 4a shows fabric 2 after the flame spread test and Figure 4b after the arc test at 4 kA.

Fabric 11 was a light aramid fabric meeting well the code letter A requirement of



(a)



(b)

Figure 3. Electric arc test (a) at the beginning, (b) after ignition.

EN 531:1995 [6]. In arc testing it hardened, changed colour, and hot metal drops penetrated the fabric. The warp of fabric 6 was FR cotton and the weft of FR polyester. The weft melted in

both tests, but the construction was evaluated as unbroken before touching the sample. The least changes in the arc test at 4 kA were found for fabrics 1, 3, 7, 9, 10, 12 (Table 2).

TABLE 2. The Behaviour of Fabrics in the Flame-Spread Test and in the Electric Arc Test

Fabric No.	EN 532:1994 [13]	ENV 50354:2001 [10] 4 kA	ENV 50354:2001 [10] 7 kA
1	A code met	Charred on surface	Charred through, broke when touched
2	Four of 6 samples continued to burn	Hardened, some shrinkage, some tearing	Hardened, broke
3	A code met	Became sooty, small charred spots	Charred, no holes
4	Melted up to edges	Melted	—
5	A code met	PES thread melted, CO charred, no holes, under side became dark, some shrinkage	PES threads melted, CO charred, broke when touched
6	Four of 6 samples continued to burn	Some hardening, no holes	Hardened, charred
7	A code met	Charred, hardened, no holes	—
8	A code met	Charred, hardened, no holes	—
9	A code met	Charred, no holes	Charred through, after aflame time of 3 s
10	A code met	Charred, hardened, no holes	Charred partly through
11	A code met	Hardened, small metal drops through, colour changed	Small holes >5 mm
12	A code met	Hardened, colour changed	Holes formed

Notes. CO—cotton, PES—polyester

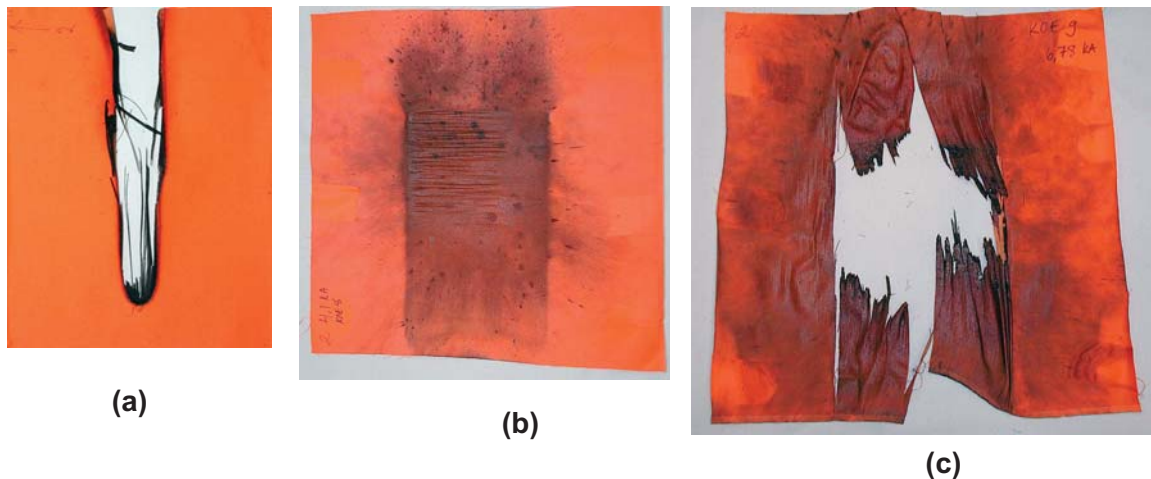


Figure 4. Fabric 2 after the tests: (a) the flame-spread test, (b) the arc test at 4 kA, (c) the arc test at 7 kA.

3.2. Flame Spread Testing in Relation to Arc Testing at 7 kA

Only part of the study fabrics were exposed to the higher current of 7 kA. At this level all tested fabrics charred and hardened. Figure 4c shows material 2 after the arc test at 7 kA. The fabric broke totally. Of the materials tested at 7 kA, FR cotton fabric 3 met the requirement best. Aramid fabric 12 met the after flame requirement well, but the small molten metal drops produced by the melted electrodes penetrated the fabric.

4. DISCUSSION

Exposure to the flame is totally different in these two methods, in EN 531:1995 [6] a flame of 15 mm and 800 °C is directed for 10 s, and in ENV 50354:2001 [10] an arc the temperature of which can be as high as 6000–10000 °C is directed for 0.5 s at the test material or garment. Even though the temperature in the arc test is much higher, it seems to be at a current of 4 kA less demanding than the flame spread testing. Particularly materials that contained a large amount of melting fibres, and therefore tended to shrink or melt, did not pass the flame spread test. In the arc test the exposed surface only hardened.

Small metal drops of the melting electrodes adhered to the surface especially of aramid fabrics, and went through thinner fabrics. In an accident situation this apparently does not always increase the hazardousness of the burns, because the drops tend to adhere to the fabric and cool down.

The results show that the arc test at 7 kA is clearly a much more demanding test than the flame spread test. The results also highlight the importance of the type of under layer fabric material. If a one-layer FR outer fabric breaks open, it exposes the under layer to the possibility of flaming ignition and, in the case

of synthetic material, to melting and dripping which worsens the consequences. King has concluded in his study on electric arcs that two layers appear to be more effective, but only if both layers contain FR fabrics with different softening temperatures. Therefore he sees, e.g., combined layers of aramid and FR cotton to be particularly effective [15].

The fabrics tested in this study were of normal 100% cotton, cotton blend fabrics and 100% aramid fabric. It would be interesting to include also wool, FR viscose, and newly developed aramid blend fabrics in the study.

5. CONCLUSION

If the fabric met the code letter A requirements of EN 531:1995 [6], it also met the class 1 requirement according to ENV 50354:2001 [10]. At a higher testing current of 7 kA, significant differences were found. The fabrics tended to char through, or a hole formed.

This comparison of tests shows that by simpler flame spread testing available in many laboratories it is possible to evaluate the flammability of materials for low-risk level electric arc exposure. But at higher current levels most normal FR fabrics break open, and then the heat resistance of the under layer fabric plays an important role in protection.

The additional advantage of the expensive arc test is the possibility to measure also ready-made garments. In such cases the design of the garment can be evaluated in electric arc exposure.

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