Testing the Electrical Resistance of Materials for Protective Footwear Production

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Abstract. This paper substantiates the relevance of testing the antistatic properties of protective footwear. It shows how an increase in temperature may affect the electrical resistance of a material.

1. Introduction
Electrostatic fields (ESF) are among the key contributors to health deterioration in blue-collar workers. In some industries, the ESF intensity of equipment far exceeds the permissible levels. Oil and gas refineries are the most hazardous facilities in this respect, as the ESF intensity there may reach or even exceed 300 kV/m, whereas the maximum permissible level is 15 kV/m [1-10].

China University of Petroleum’s specialists [11] studied the accidents associated with the effects of static electricity that had occurred in oil and gas storage and transport. They found out poor grounding and static electricity on human bodies to be the second and the third most frequent cause of accidents: 24% and 13% of all cases, respectively [12]. This is why electrical resistance of footwear is important.

The electrical resistance of antistatic protective footwear between the heel pad and the outsole should be $10^2$ to $10^5$ Ohm [13, 14]. According to [15,16], footwear can be classified into:

- antistatic conductive footwear: $10^2$ to $10^3$ Ohm;
- antistatic dissipative footwear: $10^3$ to $10^6$ Ohm;
- insulating footwear: $10^6$ Ohm or above.

Protective footwear features a multicomponent design; its antistatic properties arise from the materials used for some parts of such footwear: composite fibrous-porous materials [17], woven and nonwoven materials [18].

When at work, the ambient temperature and the inner temperature of footwear may alter within an acceptable range, which, however, will affect the conductivity of its materials.

2. Statement of problem and experimentation
To find how changes in ambient temperature affect the surficial specific resistance, the research team tested several composite multilayer, woven, nonwoven, and fibrous-porous materials used in shoemaking and supposed to have antistatic properties; see Table 1 for specifications.
Table 1. Material specifications.

| Specimen # | Name                                                                 |
|------------|----------------------------------------------------------------------|
| 1          | Two-layer composite: microfiber for the top layer, PU foam for the bottom layer (graphite-filled on the microfiber side) |
| 2          | Two-layer composite: microfiber for the top layer, PU foam for the bottom layer (graphite-filled on the PU side)        |
| 3          | Graphite-filled polyurethane foam                                      |
| 4          | Woven material: 100% K29 Kevlar®                                       |
| 5          | Woven material: 99% polyester, 1% conductive carbon fiber               |
| 6          | Woven material: 99% cotton, 1% conductive carbon fiber                  |
| 7          | Nonwoven material: 98% polyester, 2% conductive carbon fiber            |
| 8          | Real leather coated with a standard finish                             |
| 9          | Real leather coated with a 7.4% aluminum suspension finish              |
| 10         | Real leather coated with a 37% aluminum suspension finish with a second layer of standard finish                          |
| 11         | Real leather coated with a 37% aluminum suspension finish              |
| 12         | Real leather coated with a 37% aluminum suspension finish with a second layer of standard finish and a third layer of nitrocellulose varnish |

A VKG A-770 unit was used to measure the electrical resistance of materials. The unit can measure resistance in a range of $10$ to $10^{14}$ Ohm [19]. Figure 1 shows the measurement diagram.

Surficial electrical resistance is calculated by the formula presented in GOST R 53734.2.3-2010 [20].

For the experiments, the specimens were heated to 20°C, 25°C, 30°C, 35°C, and 40°C, measuring the electrical resistance every 5°C. For experiments, the researchers sampled at least 6 specimens of similar materials. The experiment results were processed using standard methods of mathematical statistics.

Figure 1. Point-to-point resistance measurement [19].
3. Results and discussion
Data collected by the experiments is shown in Figures 2 to 4.

The graphs show that synthetic materials (Figure 3, Specimens 1, 2, 5, and 7; Figure 4, Specimens 3, 4, 5) have electrical resistance as a linear function of temperature in the tested temperature range, whilst natural materials showcase either nonlinear (Figure 5, Specimens 8 and 9) or linear dependence (Figure 5, Specimens 10 to 12), depending on the finish.

Figure 2. Electrical resistance as a function of temperature, Specimens 1, 2, 6, 7.

Figure 3. Electrical resistance as a function of temperature, Specimens 3 to 5.
Increasing the temperature from 20°C to 40°C caused the electrical resistance to rise by a factor of 1.3 in Specimen 1, 1.6 in Specimen 2, 1.4 in Specimen 3, and 1.8 in Specimen 4. In Specimens 5 to 7, heating caused the electrical resistance to drop by a factor of 1.3 on average, and by a factor of 2 in Specimens 8 to 12. This data has been compiled into Table 2.

**Table 2.** Electrical resistance of the specimens.

| Specimen # | Electrical resistance, Ohm |
|------------|---------------------------|
|            | Range 10^2 … 10^5 | Range 10^5 … 10^8 | Range 10^9 … 10^14 |
| 1          | 16*10^3           | 1.1*10^5           | 2.9*10^9           |
| 2          | 2.3*10^3          | 5.4*10^7           | 7.9*10^10          |
| 3          | 1.6*10^3          | 1.0*10^8           | 6.4*10^10          |
| 4          |                   |                   | 1.7*10^11          |
| 5          |                   |                   | 6.6*10^10          |
| 6          |                   |                   | 1.3*10^11          |
| 7          |                   |                   | 6.7*10^10          |
| 8          |                   |                   |                   |
| 9          |                   |                   |                   |
| 10         |                   |                   |                   |
| 11         |                   |                   |                   |
| 12         |                   |                   |                   |
The table has three color codes for different types of antistatic materials. Yellow are conductive materials ($10^2$ to $10^5$ Ohm), green are dissipative materials ($10^5$ to $10^8$ Ohm), and orange are insulating materials that are not suitable for antistatic footwear because they tend to accumulate static charge and are therefore not intrinsically safe ($10^9$ to $10^{14}$ Ohm). Apparently, materials of Specimens 2 and 3 are the best for antistatic footwear, since their indicators are within the range set forth in GOST R 53734.4.3-2010 (IEC 61340-4-3:2001) [15], whilst Specimen 7 is on the border of dissipation.

4. Conclusions
Thus, this paper shows the electrostatic safety of footwear is determined by the materials and the environmental factors, which should be borne in mind when developing new materials for protective antistatic footwear.

Resistance has been found to be a function of temperature at 20°C to 40°C; recommendations on the choice of material for industrial footwear are given in the paper.

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