Design of thermal-resistant special clothes in three-dimensional environment

I A Petrosova¹, N I Konstantinova², E G Andreeva¹, E S Bokova¹ and G M Kovalenko¹

¹Kosygin State University of Russia, Moscow, Russia
²FGA FSRI MES of Russia, Balashiha, Russia

E-mail: 76802@mail.ru, konstantinova_n@inbox.ru, elenwise@mail.ru

Abstract. The article is devoted to fundamental and applied research in the field of fire safety of textile materials. The purpose of this work is the design and creation of special-purpose clothing, involving the effects of electricity and / or elevated temperatures, by: scientifically-based selection of fabrics and accessories with protective properties. Special design solutions were developed to protect the most likely sites of injury. The authors completed the studies to assess the quality of planting samples of heat-resistant products confirmed that the magnitude of the increments, calculated taking into account the dynamic movements and properties of heat-resistant materials, provide high ergonomic characteristics and ease of use of clothing when performing professional duties in extreme conditions involving the effects of electricity and elevated temperatures. At present, the process of 3D representation of the external basic shape of the product has been studied to the greatest extent since simple silhouette shapes of the clothing can be mathematically described. The surface of the outer clothing can be described by silhouette projections in the frontal and sagittal planes, horizontal sections, as well as informative points located on the contours of the sections characterizing the silhouette. The quantitative characteristics of the shape of the designed product in three dimensions can be magnitudes of projection increases as the gap between the skin and the clothing. In addition, such parameters of horizontal section contours as the spatial gap and its angular measure facilitate the process of describing behavior of the material in the finished product relative to the surface of the person's figure. According to the above mentioned aspect, it is obvious that the three-dimensional scanning method can be a tool not only for studying the behavior of heat-resistant materials in special clothes to protect against an electric arc, but also it allows creating an actual database of properties of heat-resistant materials.

1. Introduction

Heat-resistant protective clothing is used. It is designed for military, firefighters, utility and industrial fields [1], emergency services [2] and first responders in order to protect against intense heat exposure during performance. The use of heat-resistant clothing is aimed at preventing burn injuries, heat stress and reducing the risk of death due to thermal effects on the human body [3, 4].

One of the reasons hindering the development and use of three-dimensional (3D) automated clothing design systems in the clothing industry is the lack of a reliable database of the properties and behavior of various materials. This issue is particularly relevant for the design of special-purpose clothing, operated under extreme conditions and involving the effects of electricity and / or elevated temperatures, etc. Such clothing, in addition to solving functional tasks –it ensures work safety in case
of electric arc and ignition hazard, it also should provide comfort wear and do not cause discomfort when making necessary movements in the working poses.

Thus, design and creation of special-purpose clothing require setting and solving a set of tasks, which include not only a scientifically-based choice of fabrics and accessories with protective properties, but also the development of special design solutions that protect the most vulnerable areas, weight reduction and ease of movement performed by a worker.

The solution of such multicomponent problem is promoted by the use of modern three-dimensional tools for assessing the quality of designed heat-resistant special-purpose garments in three-dimensional environment (Fig. 1).

Three-dimensional environment which includes: creating a database (DB) of heat-resistant material properties; formation of requirements for the composition of materials in design of heat-resistant clothing; the creation of DB for dynamic effects of dimensional signs, which can change when performing characteristic movements by people at risk of an electric arc; recalculation of constructive additions taking into account the properties of the materials used and the dynamic effects of dimensional signs; construction of ergonomic heat-resistant clothing; quality assessment of design solutions in three-dimensional environment.

Figure 1. Conceptual model of the formation and evaluation of the quality of clothing fit, taking into account the properties of materials used

2. Literature review

Power line technicians [5–7] who need protection from electric arc exposure and fire with appropriate arc protective clothing [8] are most subject to dangerous situations such as risk of severe burns and electrical contact injuries. An electric arc is a flash of electric current between conductors through air, which emits thermal energy, depending on the strength of the current, duration and length of the arc [7], and which is able to ignite conventional materials and cause burns. Standards define “thermal hazard as the heat energy sufficient to cause burn injury to human tissue subjected to a momentary electric arc” [9].

Work on power lines can be executed both under voltage and in de-energized conditions, when a human can be electrocuted, or a thermal flash from an electric arc can cause burns or serious injury. Such situations are sudden, incidental and invisibly dangerous [10]. Therefore, while working with electricity, it is especially important to observe proper safety rules and use appropriate personal protective equipment (PPE) [10–12]. Flame-retardant clothing helps workers avoid accidents and injuries during electric-arc accidents [13]. Careful application of established safety standards for protection from electric shock and heat exposure, including the use of appropriate personal protective clothing (PPC), increases the safety of staff working near electrically conductive circuits [14]. As the
culture of labor protection and safety is developing, the demand for high-performance heat-resistant clothing has increased [4].

The reliability of the virtual model of the designed product largely depends on the prediction of the behavior of the materials on the figures of different constitution. Most modern CAD systems clothing contains a module simulating the behavior of the fabric in the product and considers some material properties, both visual (color, texture, ornament) and mechanical (stretching on the base and weft, flexibility, surface density, thickness, maximum stretching, etc.). There is a close relationship between the distribution and the size of the air gaps in clothing and the mechanical properties of various fabrics, established by 3D scanning, subsequent 3D visualization of clothing models and computer processing of graphic data. Air gap space in clothing is positively correlated with bending stiffness, the length of the garment and the density of the base (stiffness-bending, length and warp density) [15]. In many 3D design systems, a certain database of materials is already laid. Any user can add any information to it. For correct 3D modeling of fabrics that accept an ambiguous spatial configuration in clothes, it is possible to use the links between the parameters of the embroidered and scanned sample of the finished product and its 3D model obtained by virtual design, on the basis of which the database of material behavior in space is formed [16].

To assess thermal protection of clothing 3D scanning method is used. This method measures the distribution of thickness air gaps between the protective clothing and the skin [17, 18]. The distribution of the thickness air gaps affects the temperature resistance of clothes, since they participate in heat exchange under clothes and help to achieve thermal balance. Increasing the thickness of the air gap between the protective clothing and the skin makes it possible to reduce the effect of heat flow on human skin during both dry and moist thermal effects. The study results of the distribution of air gaps in heat-resistant clothing using a three-dimensional scanner showed that the thermal protection of clothing depends on the nature of uneven distribution of air gap sizes, which is influenced by the silhouette and style of clothing, the contour of the human body [18] and the degree of thermal shrinkage of the material [17].

At present, the process of 3D representation of the external basic shape of the product has been studied to the greatest extent [19] since simple silhouette shapes of the clothing can be mathematically described [20]. The surface of the outer clothing can be described by silhouette projections in the frontal and sagittal planes, horizontal sections, as well as informative points located on the contours of the sections characterizing the silhouette. The quantitative characteristics of the shape of the designed product in three dimensions can be magnitudes of projection increases as the gap between the skin and the clothing. In addition, such parameters of horizontal section contours as the spatial gap and its angular measure facilitate the process of describing behavior of the material in the finished product relative to the surface of the person's figure.

Based on the above mentioned aspects, it is obvious that the three-dimensional scanning method can be a tool not only for studying the behavior of heat-resistant materials in special clothes to protect against an electric arc, but also it allows creating an actual database of properties of heat-resistant materials.

3. Materials
The authors studied two groups of materials:

The first group consists of fabrics based on cotton, viscose, cellulose and wool yarns, including those based on Zirpro® fire-resistant wool, Lenzing FR® cellulose, which have moderate or high heat resistance and fire resistance;

The second group of fabrics is based on para-aramid, meta-aramid and polysulfonamide yarns P-140, Nomex®.

4. Methods
Research methods are based on the analysis and synthesis of theoretical and practical material, grouping and comparison, and a systematic approach. The theoretical foundations of metrology, image processing and computer vision methods are used in the work. In the course of the study, methods of
systematization and classification, expert assessments, engineering methods for obtaining unwinds of clothing parts for typical and individual figures were used.

For obtaining three-dimensional models, methods of three-dimensional scanning of a human figure were used, and for solving visualization problems and operations on three-dimensional images, free software libraries of Graphics Magick and VTK and a number of specialized CAD software were used.

The flammability of the tissues was determined according to ISO 15025, the heat-shielding efficiency with an open flame – according to ISO 9151, the heat-shielding efficiency with heat radiation – according to ISO 6942.

5. Methodology
Thermal stability of materials and material packages are investigated in this study and the results that formed the basis of a database of their properties in a three-dimensional clothing design system are obtained.

Speaking about the requirements for heat-resistant materials, we must first proceed from the specific conditions of usage. The specifics of work in energy industry imposes requirements for the protective suit of power engineering operators, the main features are the following: preservation of thermo-fire-resistant properties throughout the entire service life, convenience and lightness, environmental friendliness, hygroscopicity and breathability of used fabrics and materials. Special fire-resistance requirements and test methods for both the suit's top material and the clothing package as a whole are established by technical regulations and a number of regulatory documents [21–32].

The standards define the requirements for clothing materials that protect from an electric arc, including thermal stability, flame resistance for 2 seconds after ignition, the fabric should not melt, drip, peel and ignite, get fit more than 10% within 5 minutes at 260 °C [9]. Thermal resistance is a primary factor in protecting a human body from flames and extremely high temperatures [33]. In addition, heat-resistant materials which protect against thermal hazards of an electric arc must have constant thermal properties, providing protection against the incident energy of an electric arc effect of at least 20 cal/cm² (protection level 3 [34–36]), also they ensure heat protection efficiency energy of at least 20 cal/cm², and must be resistant to the effects of an open flame and don’t melt. It is important to preserve the heat resistance of clothing after 5 and 50 washings.

Heat-resistant materials are characterized by diversity, effectiveness of protection and suitability for workwear [37], can be woven and non-woven constructions [38]. Today, the market for arc-rated textiles is one of the fastest growing in the world for protective clothing [39], it is regulated by IEC, ASTM, ISO and other national standards [9, 34–36, 21–32]. It should be noted that when choosing heat-resistant clothing it is the consumer who is responsible for determining the appropriate level of protection, based on the actual conditions of use and load [40].

Fire resistance is provided either by incorporating fibers with inherent fire resistance into clothing, or by applying flame retardant treatment to fibers that are usually flammable [3]. Heat and flame resistant textiles can be divided into two groups according to the main components of the fibers.

The first group of textiles consists of cotton, viscose, cellulosic, wool and certain man made fiber-containing fabrics, including flame resistant wool Zipro®, cellulose Lenzing FR®, which have moderation to high heat and flame resistance and are available at a reasonable price [41–44]. Currently, flame resistant cotton is popular [2]. The operational limitations of these materials are associated with the heating of the fibers and the need for treatment with flame retardants [43].

The second group includes aromatic and carbonized fibers, which are distinguished by mechanical stability, high cost and low environmental friendliness due to difficulty to recycle [43]. The following materials should be distinguished: para-aramid and meta-aramid materials, P-140, Nomex®, polysulfonamide, which are characterized by strong thermal shrinkage and reduction of heat resistance after multiple exposures [2, 8, 41, 45]. The combination of para-aramid Kevlar® fiber with polybenzimidazole [2] is characterized by good thermal stability. CarbonX® carbon fabric for heat and fire-resistant clothing does not burn, char, shrink or decompose when exposed to flame, arc flash
or high heat [1]. Waterproof materials such as Neoprene / Nomex and PVC / Nomex / Kevlar [46] are used for flame resistant clothing. Waterproof heat-resistant clothing made of Hypalon® rubber-coated material and of batt-type material has a relatively long protection time, depending on the level of heat flow [47].

The combinations of flame retarded char-forming fibers and intumescents leads to an increase in thermal and fire resistance. Intumescent combinations are especially effective when based on more cost-effective and environmentally acceptable raw materials [43].

Interpolymer complexes (IPC) based on polycarboxylic acids and non-ionic polymers, stabilized by hydrogen bonds are of great interest. [48] Modifying compositions based on IPC of polyacrylic acid with non-ionic polymers (polyvinyl alcohol, polyethylene oxide, polyacrylamide) are presented in this study, the conditions for the formation of polymer-polymeric complexes in the aquatic environment are considered and a method of impregnating fabrics like canvas with stoichiometric and non-stoichiometric composition is proposed. The possibility of regulating the weight gain of the IPC in the structure of the tissue and the effect of the IPC on increasing the oxygen index of materials, reducing their inflammability and ability to maintain independent combustion are shown.

It is not recommended to use such thermoplastic fibers as polyester, polypropylene and polyamide), which, despite flame retardants functions during the polymerization and / or extrusion process, melt and / or form holes when exposure to flame, therefore, they do not meet the requirements for fabrics for protective clothing [43].

The composition of fibers has a greater effect on relative humidity of the microclimate underneath the PPC and the total clothing insulation [41]. With prolonged thermal exposure, thermal energy can accumulate inside multilayer protective clothing, which leads to a decrease in level of protection expected [49]. To improve thermal insulation, we can increase the thickness of a fabric or a package of materials [2, 47, 50], but with an increase in fabric weight physical load increases, the level of physiological stress of workers increases [51, 52] and, as a result, their performance [41].

The innovations of heat-resistant materials are associated both with their high functionality and performance in protection against flame and heat as “smart” textile materials [38] develop. The Teflon® treated fabrics in addition to heat resistance, have stain and water repellency properties and a low level of energy absorption [53]. The development of systems of intellectual thermal protection based on the use of thermal sensors and programs with algorithms of intellectual behavior is known [54]. In case of flame, a sensor installed in protective clothing can mechanically activate protective components, for example, enable the quick release of a liquid flame retardant through a vinyl tube sewn into clothing to create a protective barrier around the human’s face and neck when unexpected heat exposure [5].

When choosing the fabric for power engineers, along with the effectiveness of its fire protection, the surface density of the material, hygroscopicity and breathability, strength were considered. Table 1 shows the results of studies for heat-resistant materials used in some models of summer and winter clothing of electric welders.

As it follows from the data in the table, when choosing an effective fire-resistant fabric for the top of the clothing, it is possible to model any type of clothing for power engineers, depending on the environmental conditions that meet the standardized requirements. As a rule, only the index of thermal diffusivity changes (group B1–B5) since its measurement is directly related to the conditions of heat transfer through a package of materials and is characterized by its thermal-physical characteristics.

In addition to the requirements for the main material of the clothing, there are requirements for auxiliary materials, such as threads and accessories. The requirements for sewing threads used to manufacture protective clothing against the thermal effects of an electric arc should eliminate their melting and provide resistance to high temperatures and chemical cleaning.

Regarding the accessories, external metal parts are excluded from the clothing set. If it is impossible to avoid such accessories as zippers, buttons, etc., then they should be covered both on the external and internal sides with heat-resistant material. In addition, the design of the clothing should provide the
ability to quickly remove it after the impact of an electric arc due to preserving the functions of accessories.

**Table 1. Study of heat-resistant properties of materials and material packages**

| Name of the material (package of materials), their characteristics | The value of parameters according to the classification |
|---------------------------------------------------------------|-----------------------------------------------------|
| ISO 15025, ISO 9151, ISO 6942                               | Flammability ISO 15025 | Heatproof effect with open flame ISO 9151 | Heatproof effect with heat radiation ISO 6942 |
| Nomex fabric, $\rho = 220$ g/m², heat-resistant knitted fabric, $\rho = 220$g/m² | Group A | B2 | C2 |
| Nomex fabric, $\rho = 220$ g/m², heat-resistant fabric, $\rho = 135$ g/m²-insulation, $\rho = 150$ g/m²-windproof fabric, $\rho = 150$ g/m²-insulation, $\rho = 150$ g/m² | Group A | B5 | C2 |
| Heat-resistant fabric, $\rho = 135$ g/m²               | Group A | B2 | C2 |
| Fabric of fire-resistant mixed fibers, $\rho = 300$ g/m² | Group A | B2 | C2 |
| Heat-resistant knitted fabric, $\rho = 220$ g/m²         | Group A | B4 | C2 |
| Fabric from fire-resistant mixed fibers, $\rho = 300$ g/m² | Group A | B2 | C2 |
| 2 layers – modacrylic fiber, quilted with cotton lining, fabric made of fire-resistant mixed fibers, $\rho = 400$ g/m² | Group A | B4 | C2 |

The next stage of research is the development of design features of clothing for performing work under the conditions of high-temperature flow and high-voltage impacts.

The methods for designing materials and clothing are important for obtaining optimum thermal protective performance of clothing and ensuring the physiological comfort of workers [4, 55, 56]. Design criteria include the level of thermal protection of clothing, the functionality of the design, the requirements for physiological and psychological comfort, the efficiency of production and maintenance [45].

The temperature of the human body during work under hot conditions is influenced by arc-flash and fire-resistant AFR clothing [6, 47, 60]. Sets of protective heat-resistant clothing have a single-layer or multi-layer construction consisting of a combination of fire-resistant outer layers with inner layers of natural or artificial fibers [6]. Under electric arc conditions, flame-resistant rainwear is effective [46].

A small but significant impact on the temperature resistance of clothes is exerted by the completeness, fitting and fasteners [45]. Better thermal protection provided free silhouette than close-fitting; tight fitting adjustable cuffs on sleeves and legs were more effective than zippers; and a stand-up collar better protected the neck than a turn-down collar. In practice, thermal protection sets consisting of a one-piece jumpsuit and two-piece trousers and jackets are used oftener. According to some researchers, the smallest thermal protection was provided by two-piece set of jackets and pants, one-piece jumpsuit is slightly better and the best protection is by a two-piece overall, mainly due to the effect of layering [45]. According to other researchers, on the contrary, a two-piece set of fire-resistant material contributes to greater heat removal [56]. A variety of recommendations on the completeness of heat-resistant clothing predetermined further research in the field of consumer preferences.

It is known that most of the electricity companies use protective heat-resistant clothing in the form of a set consisting of a jacket and trousers or a jacket and semi-overalls for the employees. Indeed, as shown in the survey, aimed at studying consumer requirements for protective heat-resistant clothing [57], 153 electricians aged 20–45 gave the greatest preference to the set consisting of a jacket and semi-overalls, which provide an opportunity to work in a more comfortable way than trousers or overalls.

The first place consumers gave to the quality of heat-resistant materials, which do not sustain combustion and do not melt after exposure to a thermal arc.

Experts chose patch pockets on the front of the heat-resistant jacket and on the sleeve, which are located as follows: two pockets are at chest level, two pockets are at waist level, one pocket is at the top of the left sleeve.
The most comfortable and providing the greatest protection of the neck, electricians consider the collar "stand", and the most convenient fittings for taking off the set are a zipper and Velcro tape.

Heat-resistant clothing should not only protect from dangerous temperature conditions, but also be comfortable, fit, provide mobility of the employee. Therefore, in addition to the regulatory requirements for thermal protection, it is important to design dynamic garment [5]. It is known that the convenience of operating protective clothing during the work in enclosed spaces and in open areas provide ergonomic performance. The design of ergonomic clothing takes into account the thickness of materials and the dynamic effects of sizes [58].

Anthropometric studies of male electricians, who were attended by 103 people, aged 20 to 45, their work was under observation during the shift, as well as photo and video recording of characteristic movements and postures of electricians are done. A list of characteristic movements was drawn up, among which are the following: climbing a power line – (Fig. 2, a), working on a pole (Fig. 2, b), working with an electric shield while standing (Fig. 2, c) and in a half-squat.

![Figure 2. The characteristic movements of electricians: a – climb the pole, b – work on the pole, c – work with an electrical shield](image)

A list of sizes, which can increase and decrease during characteristic movements, is made. The scheme of measurements in dynamics for the characteristic movement “Work at an electric board while standing” is shown in Fig. 3, a. With the help of 3D scanning, measurement of dimensional signs of men’s figures in statics (Fig. 3, b) and dynamics (Fig. 3, c) was performed. Subsequent studies were performed both for naked body and in clothing made of heat-resistant materials.

![Figure 3. Study of a figure using three-dimensional scanning: a – research in statics, b – research in dynamics](image)
The measurements were carried out in accordance with the methodology of anthropometric research which are given in recommendations on the standardization of the adult and child population. Maximum and minimum dynamic effects are calculated by the formula (1).

\[ d_i = \frac{X_i^{(d)} - X_i^{(s)}}{X_i^{(s)}} \times 100\% \]  

where \( d \) is the dynamic effect of the \( i \) figure \((i = 1, 2, \ldots n)\), cm; \( X_i^{(d)} \) – the value of the dimensional sign in the dynamics of the \( i \)-figure, cm; \( X_i^{(s)} \) the value of the dimensional sign in statics of the \( i \)-figure, cm.

The detected values of changes in dimensional signs in dynamics were used to determine the movements, taking into account the properties of the material used in the design of heat-resistant protective clothing. The calculation of increases in movement is made according to the formula (2)

\[ IM = \frac{(d_i - \varepsilon)}{100\%} \times Nc \]  

where \( IM \) – increase in movement, cm; \( d_i \) is the dynamic effect, \%; \( Nc \) is the size of the dimensional sign in statics, cm; \( \varepsilon \) is the value of conditionally residual deformation, depending on the group of tissue, \%. Heat-resistant materials belong to groups of fabrics with a value of conditionally residual deformation up to 0.5 \% [64, 65].

Regarding consumer preferences, requirements for heat-resistant clothing and research results, models of a jacket and semi-overalls for a male electrician were developed. A sketch of the model and the look of the finished garment are shown in Fig. 4. The clothing is transferred for testing.

Figure 4. Sketch of the finished heat-resistant clothing

In the final part of the work, the assessment of the quality of the of heat-resistant clothing samples and the assessment of the projection gaps between the inner layer of the package of heat-resistant materials and the human body using three-dimensional scanning are made. The calculation of the free fitting in the product was done using the SizeReader program developed at the Department of RSU named after A.N. Kosygin with the support of the Ministry of Industry and Trade of the Russian Federation [17, 18]. An increment has been established for the armhole section, both in statics (Fig. 5, a) and in dynamics (Fig. 5, b). The increase in the area of the armhole was determined as the difference in the lengths of arm sections of the diameter.
Figure 5. Estimation of projection gaps using three-dimensional scanning: a- in statics, b- in dynamics

6. Conclusion
Large increments contribute to excessive accumulation of material on the construction site, which leads to laying of folds and deterioration of the appearance of the product, small – limit the amplitude of movements. The studies to assess the quality of heat-resistant products confirmed that the increase, which was calculated with the dynamic movements and properties of heat-resistant materials provide high ergonomic characteristics and ease the use of clothing when performing professional duties under extreme conditions involving the effects of electricity and elevated temperatures.

Acknowledgments
The reported study was funded by The Kosygin State University of Russia and FGA FSRI MES of Russia, Balashiha.

References
[1] Young J 2008 Markets: Safety and protective. Taking the heat: Innovations in fire-retardant fibers and fabric products are keeping people and structures safer Spec. Fabrics Rev. 93(10) 97–100
[2] Wang M and Li J 2016 Thermal protection retention of fire protective clothing after repeated flash fire exposure J. of Industr. Textiles 46(3) 737–55
[3] Linnane D M, Fogarty A and Hunt A 2017 The effects of flame resistant protective clothing on heat exchange and thermal strain J. of Sci. and Med. in Sport 20(2) 73–4
[4] Song G, Mandal S and Rossi R 2016 Thermal Protective Clothing for Firefighters (Cambridge, UK: Woodhead Publ.) 242 p
[5] Mendoza E, Cooper J P, Evangelista J W, Auerbach M and Armas A Ö 2012 On Demand Thermal Protection (ODTP): A New Approach for Designing Garments Exposed to Flash Flame Incidents pp 2111–2120, Int. Mechanical Engineering Congress and Exposition (Houston, TX, US: ASME)
[6] Neal T E, Bingham A H and Doughty R L 1997 Protective clothing guidelines for electric arc exposure IEEE Transact. on Industry Applicat. 33(4) 1041–54
[7] Wulf K 2009 Flame-Resistant Clothing Its Role In Protecting Electric Line Workers From Arc Flash Burns Professional Safety 54(6) 685–6
[8] Doughty R L, Neal T E, Dear T A and Bingham A N 1999 Testing update on protective clothing and equipment for electric arc exposure IEEE Industry Applicat. Magazine 5(1) 37–49
[9] ASTM F1959/ F1959M – 14e1 Standard Test Method for Determining the Arc Rating of Materials for Clothing 2014
[10] Blume S W 2016 Personal Protection (Safety) In Electric Power System Basics for the Nonelectrical Professional (Hoboken, New Jersey, US: Wiley-IEEE Press) pp 209–23
[11] ISO 11999-1:2015 PPE for firefighters, Test methods and requirements for PPE used by firefighters who are at risk of exposure to high levels of heat and/or flame while fighting fires occurring in structures Part 1: General
[12] ISO 11999-3:2015 PPE for firefighters, Test methods and requirements for PPE used by firefighters who are at risk of exposure to high levels of heat and/or flame while fighting fires occurring in structures Part 3: Clothing

[13] Mäkinen H and Mustonen S 2003 Features of electric arc accidents and use of protective clothing in Finland Safety Sci. 41(9) 791–801

[14] McClung B and Mohla D C 2005 Electrical design – refined for safety Industrial and Commercial Power Systems Technical Conf. (Hoboken, New Jersey, US: IEEE)

[15] Yu M, Wang Y, Wang Y and Li J 2013 Correlation between clothing air gap space and fabric mechanical properties J. of the Textile Instit. 104(1(1)) 67–77

[16] Kenkare N, Lamar T A M, Pandurangan P and Eischen J 2008 Enhancing accuracy of drape simulation Part I: Investigation of drape variability via 3D scanning J. of the Textile Instit. 99(3(6)) 211–8

[17] Petrosova I A, Andreeva E G and Guseva M A 2019 The system of selection and sale of ready-to-wear clothes in a virtual environment pp 1–5 Int. Sci. and Technol. Conf. “EastConf” (Vladivostok) DOI: 10.1109/EastConf.2019.8725390

[18] Petrosova I A, Shantseva O A and Andreeva E G 2017 Assessment of a right size ready-to-wear clothes to the consumer’s figure in the three-dimensional system Izv. Vysshikh Uchebnikh Zavedenii, Ser. Teknol. Tekstil. Promyshl 5(371) 139–42

[19] Gazhur A A and Lukiyanchuk I N 2018 Trends of development of the sphere of services in Russia Proc. of the Voronezh State Univer. of Engineer. Technol. 80(3) 444–50 Retrieved from: https://doi.org/10.20914/2310-1202-2018-3-444-450

[20] Gurina M A and Rumyanceva J V 2019 Comprehensive tools and methodologies quality improvement in the management competitiveness trade enterprises Proc. of the Voronezh State Univer. of Engineer. Technol. 81(2) 320–35 Retrieved from: https://doi.org/10.20914/2310-1202-2019-2-320-33520.

[21] ISO 6942:2002 Protective clothing, Protection against heat and fire, Method of test: Evaluation of materials and material assemblies when exposed to a source of radiant heat

[22] ISO 11612:2015 Protective clothing, Clothing to protect against heat and flame, Minimum performance requirements

[23] ISO 12127-1:2015 Clothing for protection against heat and flame, Determination of contact heat transmission through protective clothing or constituent materials Part 1: Contact heat produced by heating cylinder

[24] ISO 12127-2:2007 Clothing for protection against heat and flame, Determination of contact heat transmission through protective clothing or constituent materials Part 2: Test method using contact heat produced by dropping small cylinders

[25] ISO 13506-1:2017 Protective clothing against heat and flame Part 1: Test method for complete garments, Measurement of transferred energy using an instrumented manikin

[26] ISO 13506-2:2017 Protective clothing against heat and flame Part 2: Skin burn injury prediction, Calculation requirements and test cases

[27] ISO 14116:2015 Protective clothing, Protection against flame, Limited flame spread materials, material assemblies and clothing

[28] ISO 15025:2016 Protective clothing, Protection against flame, Method of test for limited flame spread

[29] ISO 16073:2011 Wildland firefighting personal protective equipment, Requirements and test methods

[30] ISO 17492:2003 Clothing for protection against heat and flame, Determination of heat transmission on exposure to both flame and radiant heat

[31] ISO 9151:2016 Protective clothing against heat and flame, Determination of heat transmission on exposure to flame

[32] ISO/TR 2801:2007 Clothing for protection against heat and flame, General recommendations for selection, care and use of protective clothing
[33] Mandal S, Song G, Ackerman M et al 2013 Characterization of textile fabrics under various thermal exposures Textile Res. J. 83(10) 1005–19
[34] IEC 61482-1-1:2009 Live working, Protective clothing against the thermal hazards of an electric arc, Part 1-1: Test methods, Method 1: Determination of the arc rating (ATPV or EBT50) of flame resistant materials for clothing
[35] IEC 61482-1-2:2014 Live working, Protective clothing against the thermal hazards of an electric arc, Part 1-2: Test methods, Method 2: Determination of arc protection class of material and clothing by using a constrained and directed arc
[36] IEC 61482-2:2018 Live working, Protective clothing against the thermal hazards of an electric arc, Part 2: Requirements
[37] Brewster E P and Barker R L 1983 A Summary of Research on Heat Resistant Fabrics for Protective Clothing Amer. Industr. Hygiene Associtat. J. 44(2) 123–30
[38] Shishoo R 2002 Recent developments in materials for use in protective clothing Int. J. of Cloth. Sci. and Technol. 14(3/4) 201–15
[39] Hoagland E H 2013 Flame resistant textiles for electric arc flash hazards. Chapter In Handbook of Fire Resistant Textiles (Cambridge, UK: Woodhead Publ.) pp 549–80
[40] Doughty R L, Neal T E, Laverty G M and Hoagland H 2002 Minimizing burn injury: electric-arc hazard assessment and personnel protection IEEE Industry Applicat. Magazine 8(3) 18–25
[41] Carballo-Leyenda B, Villa J G, López-Satúé J and Rodríguez-Marroyo J A 2017 Impact of Different Personal Protective Clothing on Wildland Firefighters’ Physiological Strain Frontiers in Physiol. 8 185–7
[42] Day M, Cooney J D and Suprunchuk T 1988 Durability of Firefighters’ Protective Clothing to Heat and Light Textile Res. J. 58 141–7
[43] Horrocks A R 1996 Developments in flame retardants for heat and fire resistant textiles – The role of char formation and intumescence Polymer Degradat. and Stability 54(2-3) 143–54
[44] Mehta P N 1980 Engineered Wool Industrial Protective Clothing Textile Res. J. 50(3) 185–93
[45] Tan Y B, Crown E M and Capjack L 1998 Design and evaluation of thermal protective flightsuits. Part I: The design process and prototype development Cloth. and Textiles Res. J. 16(1) 47–55
[46] Hoagland H and Morrow B 2000 Using rainwear as switching jackets: a reasonable solution for electric arc exposure IEEE Transact. on Industry Applicat. 36(5) 1241–6
[47] Stull J O 2000 Comparative thermal insulative performance of reinforced knee areas of firefighter protective clothing In Performance of Protective Clothing: Issues and Priorities for the 21st Century vol 7 (Austin, TX: ASTM) pp 312–28
[48] Bokova E S, Kovalenko G M, Wóźniak B et al 2016 Interpolymer complexes as modifying compounds for reducing cotton blended fabric flammability Fibres and Textiles in Eastern Europe 24(6(120)) 157–60
[49] Song G, Cao W and Gholamreza F 2011 Analyzing stored thermal energy and thermal protective performance of clothing Textile Res. J. 81(11) 1124–38
[50] Dale J D, Crown E M, Ackerman M Y et al 1992 Instrumented Mannequin Evaluation of Thermal Protective Clothing ed McBriarty J P, Henry N W In Symposium on Performance of Protective Clothing. Philadelphia (PA, USA: Amer. Society for Test. and Mater. (ASTM)) pp 717–33
[51] Wen S, Petersen S, McQueen R and Batcheller J 2015 Modelling the physiological strain and physical burden of chemical protective overalls Ergonomics 58(12) 2016–31
[52] Yoo S and Barker R L 2005 Comfort Properties of Heat-Resistant Protective Workwear in Varying Conditions of Physical Activity and Environment Part I Thermophysical and Sensorial Properties of Fabrics Textile Res. J. 75(7) 523–30
[53] Devarajan S, McQueen R H and Wen S 2017 Can common finishing treatments used in chef jacket fabrics improve protection against scald injury Fashion and Textiles 4(19) 1–15
[54] Rogale S F, Rogale D, Dragčević Z et al 2007 Technical systems in intelligent clothing with active thermal protection Int. J. of Cloth. Sci. and Technol. 19(3/4) 222–33
[55] Song G, Barker R L, Hamouda H et al 2004 Modeling the Thermal Protective Performance of Heat Resistant Garments in Flash Fire Exposures Textile Res. J. 74(12) 1033–40
[56] Poirier M P, Meade R D, McGinn R et al 2015 The Influence of Arc-Flash and Fire-Resistant Clothing on Thermoregulation during Exercise in the Heat J. of Occupat. and Environ. Hygiene 12(9) 654–67
[57] Anketolog, Online questionnaire to determine the requirements of consumers to heat-resistant clothing Retrieved from: https://anketolog.ru/survey/manage/preview/153883, 2018 (accessed 07 November 2018)
[58] Martynova A I, Andreeva E G and Maksutova M T 2011 Development of a method for assessing the dynamic characteristics of the design of women's shoulder clothing Cloth. Industry 1 47–8
[59] Dunaevskaya T N, Koblyakova E B, Ivleva G S and Ievleva R V 2005 Conf. Fundamentals of applied anthropology and biomechanics ed E B Koblyakova (Moscow: MSUDT) 280 p
[60] L'vov E Eh, Zubkova N S and Konstantinova N I 2010 Justification of criteria for selection of fabrics of the upper layer of special protective clothing of workers of metallurgical enterprises Fire safety 1 90–6