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Analysis of Underwear Used with Protective Clothing Worn by Metallurgy Workers and Welders – Research Survey

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Abstract
Employees of the metallurgy industry and welders are constantly exposed to a hot factors and hot microclimate in working environment. Difficult working conditions associated with expose employees to hot factors occurring in the form of flame, contact heat, convective heat, and splashes of molten metal may consequently lead to extensive body burns and even death. Scientific publications have proven that the temperature of the working environment is an important factor affecting human safety and performance. Improved comfort and safety can be achieved by using properly selected clothing and underwear/undergarment, meeting the requirements for a specific occupational group. In order to obtain information regarding underwear/undergarments usually used under protective clothing as well as to get acquainted with expectations regarding the subject matter, questionnaire surveys were conducted among two professional groups, namely employees of the metallurgy and welders, who are constantly exposed to a hot factors and hot microclimate.

Key words: *protective clothing, underwear, hot work environment, surveys.*

Introduction

Employees of the metallurgy and welding industry are exposed to hot factors such as flame, infrared (heat) radiation, contact with a hot object or splashes of molten metal during work. Flame occurs in many types of professional activities, often being a part of the technological process. It can cause the inflammation of clothing and burns. Infrared radiation is a dangerous factor, often found in many workplaces, frequently as a side effect of processes, including metallurgy and the metal industry. Infrared (IR) radiation is optical radiation with a wavelength of 780-10.000 nm [1], exposure to which can lead to the body overheating. The employee may also be exposed to hot objects and surfaces that can reach temperatures of up to several hundred degrees Celsius, and consequently lead to body burns. Splashes of molten (liquid) metal create a threat in many workplaces. In steel mills and foundries, workers are exposed to large splashes of liquid metal, e.g. iron, aluminum, steel, zinc, silver or other metals. Working with liquid metal can cause serious and even fatal accidents [2].

Exposure to hot factors can be short or long-term and often extreme mainly in industries such as the metallurgical industry, metal and glass industry, foundries, the coke industry, etc.

Hot factors in the form of a flame and large amount of convective heat occur during the work of a welder as a result of electric arc action. Electric arcs that secrete enormous amounts of energy instantaneously are a threat to people in the vicinity. Heat emitted by an electric arc can cause clothes to ignite, melt or burst and, as a consequence, severe body burns [3, 4].

The above-described hot factors can cause serious accidents at work or burns. In addition, working in a hot environment (temperature above 28 °C) may lead to disturbances of the cardiovascular system and central nervous system, as well as to skeletal muscle contractures and dehydration of the human body [5].

For their protection and safety, workers exposed to hot factors should use personal protection equipment dedicated to their workplace that can reduce the risk associated when working with hot factors. In the case of employees of the metallurgy industry and the profession of a welder, appropriately selected and designed specialised clothing is necessary [6].

Protective clothing for industrial workers exposed to hot agents should meet the requirements of PN-EN ISO 11612: 2015-11 [7]. Clothing conforming to this standard should protect workers against short-term exposure to flame and at least one type of hot factor, such as convection heat, thermal radiation, and large splashes of molten metal. If, at low levels of heat radiation and temperatures below 50 °C, there is a risk of clothing ignition, one can use aramid yarns, (eg. Nomex®) or chemically modified fabrics: resistant to inflammation, for example: cotton (impregnated with Pyrovatex® or Proban® technology) or wool. In a work environment in which there is a high level of thermal radiation (up to 20 kW/m^2), clothing made of aluminised materials reflecting infrared (thermal) radiation is used. The construction of this type of clothing is adapted to the risk and working conditions (apron, clothing, head and neck protection). In workplaces where the intensity of radiation is higher than 20 kW/m^2, clothes made of multilayer materials or systems of materials are used, e.g. an outer layer is created from aluminised material made of glass fibres, aramid fibres, wool, cotton or viscose impregnated with inflammable material, while the inner layer is made of wool or cotton impregnated non-flammable material [5, 8].

Protective clothing for welders is very often made of cotton fabric impregnated non-flammable material with a suitable mass per square metre, usually above 320 g/m^2. Places exposed to sparks and droplets of molten metal can be reinforced with an additional layer of fabric which ensures the long life of clothing products during intensive use. Some types of protective clothing for welders, e.g. aprons and forearm protectors are made of leather. On the market there can be also found a construction of leather and fabric clothing in which the front of the garment is made of leather and the back – of textile fabric. Both the fabric and leather meet the requirements of PN-EN ISO 11611: 2015-11 [9]. This type

of clothing provides high resistance to hot factors and, at the same time, higher comfort than that made entirely of leather. The back of clothing, being less exposed to sparks and splashes of materials, does not quickly deteriorate and provides higher permeability of water vapour and air than the skin, which is important from the user's comfort point of view.

However, these requirements are applied only to outerwear, which is the most exposed to hazards [10]. There are currently no requirements for undergarments used under protective clothing. Due to the fact that it is worn close to the body and that protective clothing could increase worker safety when exposed to hot factors, undergarments are very important elements of protective clothing.

In spite of the actions constantly undertaken aimed at the protection and safety of employees residing in a hot work environment, there are and will continue to exist jobs in the future where employees face burdens caused by a hot work environment [11, 12]. A hot microclimate is defined by the operating environment conditions and is determined by the air temperature in a room of more than 30 °C and the relative humidity of the air at a level above 65%, or by direct action in rooms with an open source of thermal radiation [11]. Numerous studies have shown that the temperature of the environment is an essential factor affecting the type and extent of changes in relation to human performance during thermal stress. In addition, it was found that thermal discomfort negatively affects the quality of work [13]. Thermal stress in a hot environment adversely affects the employee's efficiency and may cause a decrease in his skills, vigilance and perceptiveness [14, 15].

Humans have the ability to defend themselves against adverse climatic conditions. They can primarily adjust clothing to the ambient conditions, and also regulate energy expenditure by changing the intensity of work performed and with breaks [16]. The most important condition for maintaining comfort is the use of such clothing that would prevent the condensation of water vapour in the sub-microclimate; hence, clothing materials should be characterised by low resistance to water vapour penetration. However, it is not only the outer clothing that determines comfort, but the all garment. As has been proven in many studies [10, 17], that clothing worn close to the body (underwear) has a significant impact on the user's thermal sensations. Discomfort associated with the use of protective clothing can be significantly reduced by using appropriate underwear or undergarments. Knitted fabrics currently available on the market show satisfactory biophysical properties in terms of their use in underwear worn in a hot microclimate. However, research on protective properties indicates that not all knitted fabrics can be used in underwear intended for use during exposure to hot agents, especially at an extreme level.

In order to identify the current situation in the field of undergarments currently worn under protective clothing by two professional groups of employees (metallurgical industry workers and welders) who are exposed to hot factors during their work as well as their requirements and suggestions in this area, a survey was carried out.

Research methodology

The survey methodology was based on the preparation and development of a questionnaire covering seven questions addressed to two professional groups of employees (metallurgical industry workers and welders), and on the analysis of survey results. The questionnaire contained six closed questions and one open question. The questions took into account the specificity of workplace conditions, habits related to the clothing and preferences as well as suggestions relating to underwear and undergarments which could be used by metallurgical workers and welders.

The survey was conducted using the traditional method. The first two questions were used to characterise the group of respondents surveyed (their completion was obligatory): they concerned the age of respondents and the length of their work.

Question No. 3 provides information on the type of clothing/underwear currently worn by both professional groups. Surveyed answers obtained allowed to determine the type of underwear and clothing which had been used so far by employees of the metallurgy and welders. This answer included traditional underwear and clothing, which included cotton underwear, a flannel shirt, underwear made of non-flammable fabrics as well as modern solutions like thermoactive underwear. The question was of a closed character, but the respondents made the multiple choice responses.

Question No. 4 was used to obtain information on the type of underwear that both professional groups would like to wear under the protective clothing while working. It was an obligatory question and, as in the case of question No. 3, the respondents answered from a multiple-choice.

Question No. 5 concerned the safety of workers in the metallurgy and during welding while working. It referred to the possibility of accidental unveiling of undergarments worn under protective clothing during work in hazardous conditions. The answer to this question was to identify whether there are situations in which undergarments worn under the protective clothing are exposed during exposure to hot factors.

Question No. 6 concerned the physiological comfort of underwear previously used by employees of the metallurgy and welding industries during their work. Question No. 5 and No. 6 were of a closed character, where respondents gave multiple-choice answers.

The last, 7th question, related to the expectations of workers in relation to clothing worn under protective clothing (undergarments and/or underwear). It concerned the specification of possible needs or suggestions for undergarments and/or underwear which both professional groups surveyed would like to use. The question was the only one that was open and the answer was optional.

Results of the survey and their analysis

15 employees of the metallurgical industry and 57 welders took part in the survey. Among the employees of the metallurgy industry, a small proportion of the 47% surveyed (7 people) are respondents aged 31-40, and 40% (6 people) aged 41-50. Respondents aged up to 30 years represent a small group of 13% (2 people) of all employees. surveyed Persons over 50 years old did not participate in the survey. Less than half of the 33% surveyed (5 people) declared that they had worked in the profession for no more than 10 years. Persons with work experience slightly longer than 10 years, from 11 to 20 years, accounted for 27% (4 people); the same result was noted for people

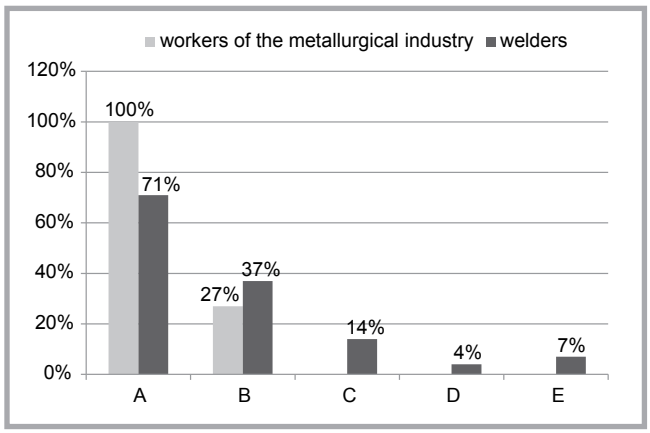

Figure 1. *Percentage distribution of answers to the question of what the respondents currently wear under the protective clothing during their work.*

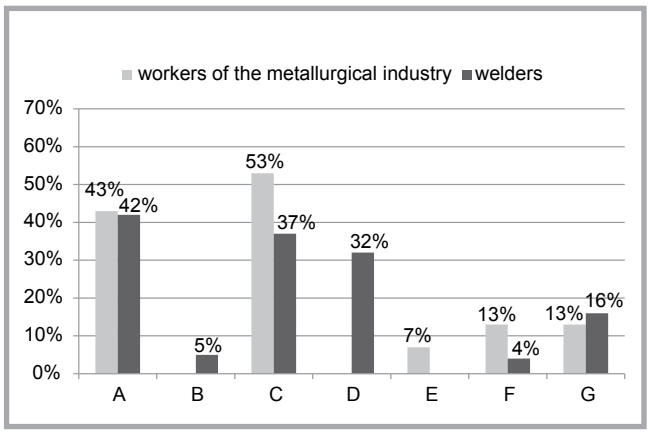

Figure 2. *Percentage distribution of answers to the question as to what kinds of undergarment would like to be worn by the respondents, while working.*

with over 21 years experience. Survey participants with the shortest work experience accounted for 13% (2 persons) of all respondents.

Among the welders, more than half of respondents – 56% (32 people) are respondents from the over 50 years' age group, while 26% (15 people) are employees aged 41-50. The smallest group – 7% (4 people) are respondents in the age group 31-40 years, whereas 11% (6 people) of all persons participating in the survey are employees who are 30 years old. More than the half of welders surveyed – 56% (32 people) declared that they had worked in the profession for more than 21 years. People with a slightly shorter working experience, i.e., from 11 to 20 years account for 18% (10 people), while 10% of respondents (6 people) are people with work experience from 5 to 10 years. Participants of the survey with shortest seniority level of less than 5 years constituted 16% (9 persons) of all respondents.

Analysing the first two questions related to the characteristics of respondents regarding the age and seniority of both the workers of the metallurgy and welders, it can be noticed that in the professional group of welders there are people who are 41 years old and older, which is associated with many years of service. In the case of employees of the metallurgy industry, there are mainly respondents aged between 31-40 and between 41-50 years old. In this group, the majority of respondents had worked in the profession no longer than 10 years, or from 11 to 20 years.

Question No. 3 concerned the identification of currently used underwear during work (***Figure 1***), for which some of respondents gave more than one answer.

The workers of the metallurgy industry 100% (15 people) reported the use of a flannel shirt, while only four people (27%) gave an additional answer that they now put on cotton underwear under the protective clothing.

Among welders, 71% (40 people) of respondents were in favour of the flannel shirt. Moreover, 37% (21 people) of the survey respondents said they now put on cotton underwear under the protective clothing. In addition, 14% (8 people) of respondents currently used non-flammable special underwear, 4% (2 people) thermoactive underwear, and 7% (4 people) another undergarment under the protective clothing during work.

Summing up, the results obtained concerning what both professional groups surveyed currently wear during work, it can be observed that metallurgy workers most often they chose a traditional flannel shirt and cotton underwear. In the case of welders, the results of the questionnaire indicate a state of knowledge associated with the possibility of improving physiological comfort, which resulted in the use of thermoactive underwear or specialist non-flammable underwear.

In both professional groups, some respondents gave more than one answer to question 'No. 4 "What type of undergarments would you like to wear under the protective clothing while working?". The question allowed to get acquainted with expectations regarding the preferences of the groups surveyed (***Figure 2***). Of the 15 workers from the metallurgy industry surveyed, more than half (53%) would like to wear thermoactive underwear with non-flammable features, 43% a flannel shirt, and 13% thermoactive underwear with phase change materials (PCM) as well as moisture absorbing underwear with superabsorbents.

One metallurgy worker would like to use underwear with a cooling system under the protective clothing. The results obtained show a slowly growing awareness among metallurgy workers in the scope of safety and the possibilities of using appropriate underwear/under garments worn under protective clothing that increase safety and comfort. However, a significant part of them gave an answer regarding the use of a flannel shirt.

In answer to the same question, among the 57 welders surveyed, fewer than half (42%) would like to use a flannel shirt, 37% thermoactive underwear with non-flammable features, and 32% cotton underwear. Under protective clothing respondents would like to wear moisture-absorbent underwear, e.g. with superabsorbents, and 5% – tracksuit clothing. In the case of welders, modern solutions represent a small percentage of answers, which may be due to habit and attachment to flannel shirts, while cotton underwear are preferred by the largest age group, which are people over 50, who are not so open to changes in their habits.

Question No. 5 (***Figure 3***) verified whether the employee is directly exposed to hot factors during work. In the case of metallurgical workers, as much as 87% (13 people) answered that during work there was no exposure of underwear worn

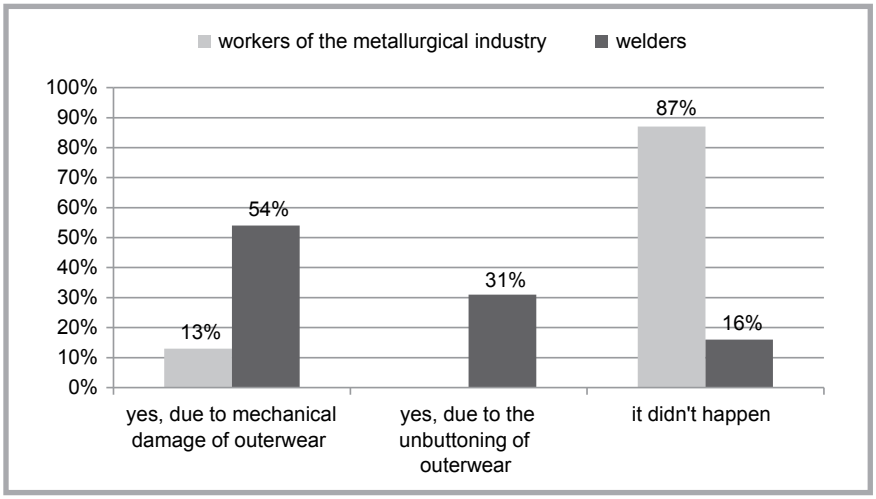

Figure 3. *Percentage distribution of answers to the question regarding the unveiling of underwear worn under protective clothing.*

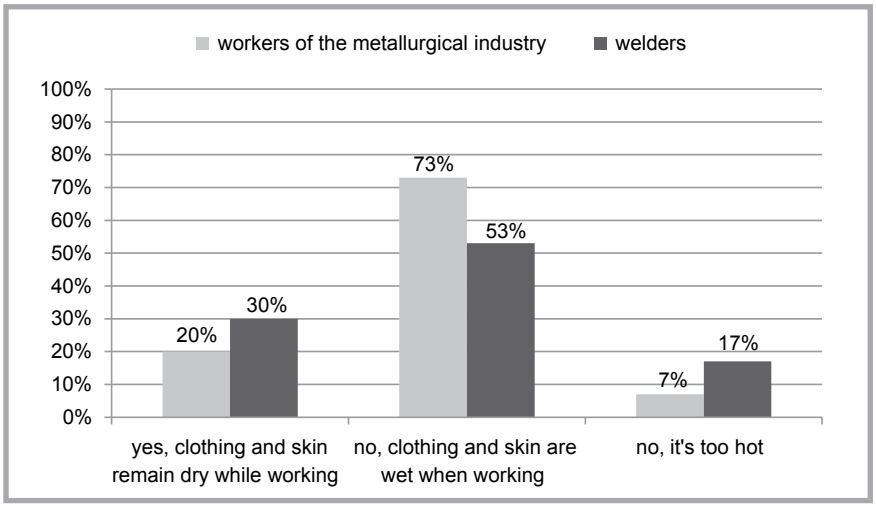

Figure 4. *Percentage distribution of responses regarding physiological comfort during work.*

under the protective clothing. 13% of all respondents (2 people) declared that the clothing worn under the protective clothing was exposed to hot factors due to the mechanical damage of outerwear.

For 54% of welders (31 people) it happened that during work the clothing worn under the protective clothing was exposed due to the mechanical damage of outerwear. 31% of all respondents (18 people) declared that the underwear worn under the protective clothing was unveiled due to the unbuttoning of outerwear. Only 16% of respondents (8 people) did not wear underwear under the protective clothing during work, whilst some others gave more than one answer.

Summing up the responses to the survey question above, in the case of metallurgy workers only a small part of people claimed that during work the underwear worn under the protective clothing was exposed due to the mechanical damage of outerwear, which may indicate suitably selected outerwear for hazards occurring at that workplace. It was confirmed by the answers given to the third question, where as much as 87% of metallurgy workers use aluminised protective clothing, and others protective clothing made of non-flammable fabric. In the case of welders, about 90% (51 people) replied that there was the unveiling of underwear worn under the protective clothing due to mechanical damage or the unbuttoning of outerwear. Both causes of unveiling the worker's body are dangerous and, consequently, can lead to deep body burns and even to the death of the employee. In order to properly protect the body of the person working in a hot environment, special undergarments worn under protective clothing should be applied characterised by specific properties that could provide the employee with safety at work and comfort of use.

Question No. 6 was asked to check whether during work in a hot microclimate employees feel physiological comfort in the protective clothing currently used (***Figure 4***). As many as 80% (12 people) of metallurgy workers gave a negative answer, claiming that the underwear /undergarments used do not provide them with physiological comfort, while 20% (3 people) feel physiological comfort, because their clothing and skin remain dry during work.

More than the half of welders surveyed-53% (30 people) gave the answer that the underwear used do not provide physiological comfort, as the clothing and skin are wet during work. Out of all respondents, 30% of the survey participants working in the welding profession (17 people), replied that their underwear/ undergarment so far provides them with physiological comfort while the clothing and skin remain dry during work. 10 persons (17%) answered that the underwear/ undergarment does not provide physiological comfort, because the participant feels too hot during work. Some respondents gave more than one answer.

As a result, it can be concluded that both groups of workers (from the metallurgy and welding industry) do not feel physiological comfort because the clothing and skin are wet, when they work. In the case of welders, the answers obtained are related to the use of cotton underwear and a flannel shirt as underwear under the protective clothing. This type of assortment condenses water vapour, leading to an unpleasant odour and loss of heat by the body. In addition, it causes the lowering of the user's comfort during physical exertion. Cotton underwear retains moisture very well due to the direct contact with the skin, which may cause a feeling of discomfort; however, the use of such an undergarment in a hot work environment can lead to body burns. In the case of metallurgy workers, the lack of physiological comfort may also be associated with the use of traditional underwear/undergarments.

The open question was aimed at getting to know the expectations and suggestions for underwear in order to design new solutions. Answers obtained in the group of employees of the metallurgy industry indicate that the design should pay attention mainly to non-flammability, thermoactivity, the ability to absorb moisture, and elasticity of underwear/

undergarments. Welders focused on the comfort of use. Great emphasis should be also placed on fire retardant properties. Welders also see the need to choose the right size and to have greater elasticity of underwear/undergarments, so that they do not limitmovement under hot microclimate conditions.

Conclusions

As a result of the survey analysis, it can be stated that in a hot environment, where the worker is exposed to the danger of hot flames, contact with hot objects and a large amount of convective heat, there is a need for innovative underwear/undergarments that would provide employees with safety and comfort of use. The surveys carried out were aimed at identifying the needs of welders and metallurgy workers in relation to undergarments worn under protective clothing in conditions with the danger of hot agents. The results obtained form the basis for determining the requirements for underwear used by the professional groups surveyed in a hot work environment.

Nowadays, the aim is to increase employee awareness in the field of safety, in particular, people exposed to harmful factors which may lead to serious and deep burns as well as bodily injuries. However, despite this fact, metallurgy workers and welders are still not equipped with appropriate undergarments which would provide them with protection against factors of hot working environment.

It should be noted that both groups surveyed in the open question paid a lot of attention to non-flammability and thermoactivity which would provide the worker with comfort of use. In addition, they suggested that clothing intended for their working conditions should absorb moisture without limiting movement during work and protect against high temperatures.

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Editorial notes

1) The term 'undergarments' is to be under – stood as the clothing worn under outer the clothing (excluding underwear).

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