FOOTWEAR USE AT WORKPLACE AND RECOMMENDATIONS FOR THE IMPROVEMENT OF ITS FUNCTIONALITY AND HYGIENE

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Abstract:

In protecting themselves against different dangerous and noxious factors at the workplace, workers are often faced with the necessity of using footwear that puts a significant strain on the human body. Such footwear is frequently not accepted by the users due to wearing discomfort and difficulties with performing one's tasks efficiently. The paper describes requirements concerning the evaluation of protective footwear functionality and hygiene as well as formulates recommendations for the improvement of these footwear properties. Based on own studies it was observed that the use of appropriate textiles in protective footwear increases its functionality and hygiene.

Keywords:

Protective footwear, comfort of use, textiles, hygiene

Types of protective footwear used at the workplace

The basic function of protective footwear is to provide protection to the lower limbs against the hazards present at the workplace. Currently, in Polish and other European research institutions, protective footwear is evaluated in accordance with relevant standards harmonised with Directive 89/686/EEC [3,29], that is, PN-EN ISO 20345:2012 (EN ISO 20345:2011), PN-EN ISO 20346:2007 (EN ISO 20346:2004) and PN-EN ISO 20347:2012 (EN ISO 20347:2012). In respect of its purpose, protective footwear may be divided into footwear providing protection from chemical agents, biological agents, mechanical agents, thermal agents, and electrocution and atmospheric agents; yet another type of footwear is used as protection from explosive materials [25].

Footwear used at the workplace may be divided into the categories of safety, protective and occupational footwear. Commercially available types of footwear are usually supposed to provide protection against several hazards at the same time, have a complex construction, and differ in terms of: the materials used (class I: footwear made of leather and other materials except for all-rubber or all-polymeric footwear; class II: all-rubber and all-polymeric footwear), model (model A – shoes, model B – ankle boots, model C – calf boots, model D – knee boots and model E – thigh boots), and mode of assembly (glued footwear, stitched and glued footwear, vulcanised footwear, injection-molded footwear (Figure 1).

Footwear may be additionally equipped with the following elements to ensure specific safety properties:

- toecaps provide protection against impact and compression,
- anti-puncture sole installed in the footwear,
- ankle protectors are shock-absorbing elements,

- metatarsal covers prevent sand, stones, sparks (in the case of welders) and molten metal splashes (in the case of steelworkers) from getting inside the footwear.

Evaluation of footwear functionality at the workplace

The introduction of requirements concerning the ergonomic properties of footwear used at the workplace in the European standard EN ISO 20344:2012 [28] was intended to make the manufacturers undertake efforts to improve the functional properties of footwear. The lifestyle changes and increased professional activity that we have witnessed over the past years have led to higher requirements concerning the comfort of use of footwear at the workplace. As comfortable sports shoes became widespread, workers also started to expect protective footwear to have similar properties [6,35]. In addition to fulfilling certain protective functions, such footwear increasingly meets strict hygienic, health-related and ergonomic standards imposed on Personal Protective Equipment (PPE) manufacturers by Directive 89/686/EEC [3]. It is one of the fundamental requirements of the Directive that personal protective equipment, protective footwear included, should fulfil the principles of ergonomics. Currently, the ergonomic properties (functionality, hygiene and comfort of use) of protective footwear are tested in accordance with the standard EN ISO 20344:2012 [28], which are harmonised with the above Directive. Footwear is evaluated by three users during an exercise test consisting of typical activities found in physical work, such as normal walking at a speed of 4–5 km/h for 5 min, ascending stairs (17 ± 3 steps) and descending stairs (17 ± 3 steps) for a maximum of 1 min, as well as kneeling and crouching.

The ergonomic properties of footwear are assessed based on a questionnaire completed by the subjects performing

Figure 1. Examples of all-rubber protective footwear for firefighters equipped with protective elements: internal steel toecaps and anti-puncture steel sole installed in the footwear. Wool felt liners are an integral part of the footwear.

Table 1. Standard questionnaire for assessing the ergonomic properties of protective footwear according to EN ISO 20344:2012

1	Is the inside surface of the footwear free from rough, sharp or hard areas that could cause you irritation or injury (feel with your hand)?	YES	NO
2	Is the footwear free of features that you consider to make wearing it hazardous? ^{*)}	YES	NO
3	Can the fastening be adequately adjusted? (if necessary) ^{*)}	YES	NO
4	Can the following activities be performed without problems: walking, climbing stairs, kneeling/crouching?	YES	NO

the exercise test. The questions concern the condition of the internal surface of the footwear, fastener adjustment and footwear-related problems with walking, ascending and descending stairs, and kneeling/crouching (Table 1).

The demand for “user-friendly” protective footwear has been consistently confirmed by literature data, including the Long Term PPE Perspective [30], which is an integral part of the Prometei initiative conducted by the leading European PPE manufacturers. This document presents a roadmap up to 2020, taking into consideration trends in designing personal protective equipment. The Long Term PPE Perspective stresses the need to improve the comfort of use of protective footwear by, e.g., incorporation of appropriate high-tech materials decreasing the weight and stiffness of such footwear. It also emphasises the need to better manage the microclimate inside protective footwear and impart antibacterial properties to textile materials used inside it (in lining and insoles). This issue is also reinforced in the latest document prepared by the Technical Committee as part of ISO [16]. According to its guidelines, the key factors in evaluation of footwear functionality should include the antifungal and antibacterial properties of footwear materials, the use of special textile and polymer materials (especially in high boots) to control water vapour diffusion and reduce the amount of sweat accumulating in the footwear, and the use of disposable socks/insoles or daily replacement of socks/insoles, which is particularly important for persons with excessive foot perspiration.

Despite the increasing requirements on the functionality of protective footwear and the efforts made by its manufacturers, such footwear is still not accepted by many workers due to wearing discomfort and hindrance to their work-related activities. This fact has been confirmed by the results of a questionnaire survey conducted among professionally active firefighters in EU countries [26].

Microclimate in footwear used at the workplace and foot health and hygiene

The application of barrier materials in footwear used at the workplace represents a formidable obstacle to heat and moisture exchange [21,22,31]. Sweat accumulation leads to increased humidity, causing physiological discomfort. Similarly, as in the case of barrier clothing, the response of the body to unfavourable environmental conditions may result in hyperthermia, disturbed thermal balance, as well as physical and mental fatigue [1,14,27].

According to the literature, the optimum conditions for the foot inside footwear consist of an air temperature not higher than 28°C–34°C and a relative humidity of 60%–65% [13]. Due to the uneven distribution of sweat glands on the foot surface, the relative humidity inside footwear varies between its various regions [34]. The highest relative humidity has been observed

in the plantar region of the forefoot, in the area of the little toe and on the internal part of the heel seat region. The amount of sweat secreted by the skin inside footwear also varies with ambient temperature, physical requirements of work, individual differences, as well as footwear construction and materials. According to literature data, the average human foot secretes approximately 2.5–3 g of sweat per hour at rest, 7.2 g/h while walking and 15.0 g/h during hard physical work [7,10,32].

Our previous studies revealed significant differences in relative humidity measured in footwear during experiments involving three types of textile liners in all-rubber firefighter footwear (Figure 2). In the case of the wool felt liners commercially provided for the firefighter footwear, relative humidity in the footwear amounted to approximately 90%. In turn, the newly designed types of liners incorporating a superabsorbent (a polymer that very dynamically absorbs liquid sweat) and an additional ventilation system in the front part of the upper reduced relative humidity levels in the studied footwear by about 20% [11,12].

In the footwear equipped with woollen liners, moisture accumulated to saturation. Thus, the study results showed that the microclimate inside the protective footwear differed depending on protective materials. Under real-life conditions of use, all the water vapour generated inside footwear containing materials constituting a barrier to temperature and moisture condenses on the skin of the foot and between the toes. This, in turn, may have an adverse effect on the foot microflora.

The growth of microorganisms is directly determined by the microclimate in the enclosed space within the footwear, that is, by its humidity and temperature. A relative humidity of 90%–100% inside footwear is a fundamental factor contributing to the proliferation of sweat-degrading bacteria [11,15]. Therefore,

analyzing the microbiological contamination of footwear, one should take into consideration the presence of pathogenic bacteria and fungi. The colonisation of internal footwear elements by yeasts of the genus *Candida* and dermatophytes constitutes a separate microbiological problem linked to foot mycosis. Other microorganisms important from the point of view of footwear hygiene are molds of the genera *Aspergillus* and *Scopulariopsis*, which are often found in moist interdigital spaces. Similarly, as in the case of bacteria, the growth of these fungi is stimulated by elevated sweat secretion, which is usually caused by wearing non-hygienic footwear impermeable to air and water vapour. Protective and sports footwear offer particularly favourable conditions for microbial development [11]. Exfoliated epidermis and sweat components decomposed by bacteria provide nutrients for fungi, which find perfect growth conditions inside footwear.

The influence of sweat on microbial growth depends on the type of footwear materials used. Textile elements inside footwear, such as insoles, lining or padding, made of natural fibres (e.g., cotton or wool) constitute an excellent substrate for the development of microorganisms. Bacteria proliferate inside footwear since the first day of its use and give rise to an unpleasant odour due to sweat degradation. They may infect all kinds of cuts and wounds, hampering the healing process. The fungi colonising footwear often lead to foot mycosis and faster degradation of footwear, causing stains and discolorations, as well as destroying footwear materials. In our previous study on the survivability of bacterial and fungal strains on different insole materials, it was found that wool fibres and the absence of a biocide significantly increased bacterial growth, which was much lower on materials made of synthetic fibres with an addition of a biocide [11].

Onychomycosis is the most widespread disease of the nails, which is very prevalent in the population. In fact, it

Figure 2. Relative humidity in all-rubber firefighter footwear used with three different types of textile liners.

is responsible for approximately half of the abnormalities detected in the nails [5,17,33]. The prevalence of onychomycosis among workers in highly developed countries is estimated at 3%–8%, depending on the population's age and the studied country. Importantly, onychomycosis of toenails is 4–7 times more widespread than that of fingernails [17]. It should also be remembered that infected nails may be a site from which a fungal infection can spread to other skin regions. Thus, efficient treatment of onychomycosis is necessary not only to contain the nail disease, but also to prevent the development of mycosis in other parts of the skin [19]. In the prophylaxis of foot mycosis, footwear hygiene as well as reduction of excessive sweating is important, as it is conducive to an increased fungal presence [4]. In turn, footwear hygiene and durability depend to a considerable degree on the biological resistance of footwear materials and conditions of use. In most cases, adequate biostabilisation of footwear materials increases their biological resistance. At the same time, biostabilisation plays an important role in the prevention of foot mycosis, as it protects materials, and, by the same token, the footwear, from colonisation by microorganisms in general, and by pathogenic fungi in particular [4].

The results of microbiological resistance tests involving bioactive textile liners used with firefighter footwear confirmed their antifungal properties against *Aspergillus fumigatus* and *Trichophyton mentagrophytes* (Figure 3). Based on test results, one can conclude that all the designed liners exhibited good antifungal properties against *Trichophyton mentagrophytes* and were classified at degree 0 – absence of fungal growth as assessed using a microscope at a magnification of 50×. This is a very good result compared with the commercially used wool felt liners (classified at degree 5 fungal growth).

Recommendations for the improvement of footwear functionality and hygiene

It is not an easy task to design protective footwear for various industrial sectors, professions and work positions, which are often involved with extreme work conditions, and which would meet all the requirements concerning protective properties, durability, hygiene and functionality [18,20].

Ensuring protective properties always deteriorates the biomechanical and hygienic properties of the footwear [2,8]. However, footwear should not exhibit features that would considerably reduce its functional qualities. Therefore, recommendations for the improvement of the functionality and hygiene of “foot-friendly” protective footwear should address the following aspects:

- Appropriate thermal insulation properties and the ability to remove moisture from the immediate surroundings of the foot are of primary importance. Footwear offering full protection to the feet may have significantly compromised physiological and hygienic properties. This in particular concerns situations involving extreme hazards, e.g., in the steelwork industry and during firefighting or chemical rescue operations. In such cases, protective footwear often makes it impossible to transport heat and perspiration, which are profusely produced during physical activity, away from the foot. High temperature and excessive humidity in the footwear lead to discomfort, which may be perceived with different intensity by different persons. If adverse microclimatic conditions in the footwear persist for a prolonged period of time, then the organic substances contained in sweat begin to decompose. This makes the skin pH more alkaline and promotes the growth of pathogenic bacteria and fungi. At the same time, due to

Figure 3. Protective effects of six variants of bioactive composite materials used in liners for all-rubber protective footwear against *Aspergillus fumigatus* and *Trichophyton mentagrophytes* compared with standard wool felt liners [11].

the swelling of the cornified layer of the epidermis caused by elevated humidity, the skin is more susceptible to abrasions and other mechanical injuries; it is also more readily accessible to microorganisms. Therefore, protective footwear materials should not only meet the protective requirements, but also physiological and hygienic standards, actively supporting the thermoregulatory processes of the human body. An adverse microclimate inside footwear hampers the thermoregulatory process in the feet, also affecting the functioning of the entire body. Thus, this process should be appropriately regulated. Protective footwear is often made of impermeable rubber or polymeric materials that prevent external water and/or chemical substances from penetrating the footwear. In this type of footwear, it is practically impossible for sweat to be transported away, and almost all water vapour condenses inside the footwear, making both the footwear itself and the socks moist. Thus, it is necessary to seek solutions that would increase the capacity of footwear to absorb large amounts of moisture produced by the feet. The use of new materials with high sorption capacity and dynamics, such as superabsorbents, in internal footwear elements (lining, inserts, liners and padding) seems to be very promising. To prevent the growth of microorganisms, footwear materials should be sanitised already at the stage of manufacturing. Some of the available materials contain bactericidal and fungicidal agents within the molecular structure of the fibre [9,23,24]. In these cases, the fibres themselves are characterised by antimicrobial properties, so these properties have a very long-life and do not wear out with footwear use (in contrast to impregnation with or surface deposition of bactericidal and fungicidal agents).

- Footwear materials should not have any detrimental effects on the users' health. The health-related properties of footwear are linked to bacteriological and toxicological issues as well as allergy hazards. According to Directive 89/686/EEC, "PPE materials and parts, including any of their decomposition products, must not adversely affect user hygiene or health." This is reflected in various standards that impose requirements as to the content of noxious substances in different materials [36].
- Footwear should exhibit good waterproof properties. It is of utmost importance that leather upper materials used in footwear worn in a cold climate should provide protection from the external action of water. As already mentioned, wet materials exhibit significantly higher levels of thermal conductivity and deteriorate the microclimate conditions inside footwear. However, the latest developments in leather tanning technology have led to leathers with very good waterproof properties combined with permeability to water vapour. Nevertheless, it is still very difficult to manufacture impermeable footwear in which all couplings, whether stitched or glued, would be waterproof. Nowadays, a popular solution is to use polymer membranes that are at the same time waterproof and vapour permeable. The disadvantage of such membranes is that they are brittle and require strong textile supports. Consequently, laminates are typically used in which the membrane proper is protected on both sides.

Summary

Personal protective equipment, including footwear, is worn or used by workers to protect themselves from one or more health or safety hazards at the workplace. In order to ensure adequate protection to the user, such footwear should meet the basic requirements concerning health and safety, implemented through design and manufacture processes. While choosing "worker-friendly footwear," one should always bear in mind ergonomic issues and make sure that such footwear fits the wearer well. It is possible to improve the comfort of protective footwear through the use of appropriate textile materials like inserts, linings and liners inside footwear.

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