



Case study of the impact of toecap type on the microclimate in protective footwear



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ABSTRACT

Protective footwear plays a critical role in work effectiveness and personal safety. It exhibits special properties due to the use of protective elements and materials, but these components may deteriorate its hygienic characteristics. This paper presents a study on the influence of toecap type on the microclimate in protective footwear (ankle boots). Toecaps made of metal and of a composite polymer material were evaluated. Changes in the footwear microclimate were monitored using a thermal foot model at a perspiration rate of about 5 g/h with and without the simulated movement function. The influence of the toecap material on the microclimate in the footwear was analyzed statistically. Under conditions of simulated movement, higher temperature and relative humidity values (about 32 °C and 90%) were recorded in the toe region of ankle boots with metal toecaps as compared to composite polymer toecaps (about 29 °C and 53%, respectively). These results suggest that protective footwear with composite toecaps ensures better ventilation of the foot during work.

Relevance to industry: The current system of harmonized standards for testing protective footwear in terms of hygienic properties concerns individual materials of which the footwear is made. It does not allow for comprehensive evaluation of protective elements in footwear under simulated work conditions. This study provides evidence that metal toecaps in safety footwear used by workers may impair specific hygienic parameters which are critical for wearing comfort and foot health.

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1. Introduction

The basic function of protective footwear is protection of the lower extremities against the hazards present at the workplace (Koradecka, 2012, 2010). Depending on the existing hazards, the footwear is made of different materials and equipped with special internal protective elements, such as toecaps protecting the toes against impact and compression, anti-impact metatarsal and ankle protectors, and anti-penetration inserts installed in the soles (Council Directive 89/656/EEC, 1989). These protective elements may be made of different materials, including steel, aluminum, plastic, and composites. However, while such elements ensure protection against adverse or noxious factors, they may induce considerable energy expenditure in the user and significantly deteriorate the microclimate around the foot inside the footwear (Koradecka and Konarska, 2002).

The footwear microclimate consists of the state of the air surrounding the foot, which is characterized by temperature and

relative humidity. The microclimate also includes the movement of air in the footwear. The optimum conditions for feet in footwear are air temperature not higher than 28–34 °C and relative humidity in the range of 60–65%.

Due to the uneven distribution of sweat glands across the foot, the relative humidity of the microclimate inside the footwear varies in different regions. The highest relative humidity has been observed in the plantar region of the forefoot, in the area of the little toe, and on the inner part of the heel. The amount of sweat produced by the skin inside footwear changes depending on the temperature of the surroundings, physical requirements of the work, the individual characteristics of the person, as well as the construction of the footwear and the material it is made of. According to literature data, the average human foot produces about 2.5–3.0 g sweat per hour at rest, 7.2 g while walking, and 15.0 g during hard physical work (Koeller, 1959; Hardy and Webber, 1972; Bergquist and Holmer, 1997; Heus and Schols, 2005; Kuklane and Holmer, 1998; Frederick, 1984; Hole, 1973).

Elevated temperature and relative humidity inside footwear may result in wearing discomfort (Hole, 1973). An adverse microclimate inside footwear facilitates degradation of the organic

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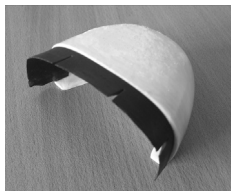
substances present in sweat, which makes the pH of the skin more alkaline and enables the growth of pathogenic bacteria and fungi (Irzmańska et al., 2012). The bacteria which develop inside footwear from the first day of its use cause an unpleasant smell due to decomposition of sweat. The fungi that colonize footwear often lead to mycosis of the feet and accelerate footwear degradation. At the same time, swelling of the cornified layer of epidermis due to high humidity makes the skin much more susceptible to chafing and other mechanical injuries during movement (Heus and Schols, 2005; Fauland et al., 2012; Gulbinienė et al., 2011; Irzmańska et al., 2010; Orlita, 2004; Ara et al., 2006; Sánchez-Navarro et al., 2011).

Efficient ventilation of the foot inside the footwear largely depends on the construction of the footwear and the material of which the protective elements are made (Koradecka, 2012). Protective elements that may hamper the free flow of heat and humidity include toecaps, which protect toes against impact and compression (Koradecka and Konarska, 2002). Although traditionally made of steel, the reinforcement can also be made of a composite material, a plastic such as thermoplastic polyurethane (TPU) or even aluminum. Toecaps should meet the protective parameters specified in relevant standards, which is essential from the point of view of the function they fulfill in protective footwear (Council Directive 89/656/EEC, 1989). However, it should be stressed that the protective properties of toecap materials are a fundamental, but not the only, condition of satisfying user requirements in terms of optimum wearing comfort. Another major issue is the influence of toecaps on the footwear microclimate, which is an important factor determining the state of foot microflora.

Non-standard evaluation of footwear microclimate has been the subject of studies conducted by researchers for many years now (Holmer, 2004). So far, research has concerned measurement of footwear microclimate under workplace or laboratory conditions with the users performing physical activity of certain intensity and at a constant temperature and humidity of the surroundings (Smith et al., 2013; Burke et al., 1994; De Dear et al., 1993; Divert et al., 2005; Bertaux et al., 2010). It should be emphasized that tests conducted directly in the workplace are difficult to carry out logistically and require a large group of subjects to achieve statistical reliability. They are usually accompanied by questionnaires aimed at obtaining information about the subjective sensations of the users. In studying footwear microclimate, physical work is simulated by walking at a given speed and for a specified period of time on an ergometric treadmill or using other ergometric equipment. The existing laboratory methods and functional tests provide many useful data but are insufficient in respect of the need to examine the microclimate in protective footwear equipped with increasingly advanced protective structures. Thus, a thermal foot model provides a useful alternative which makes it possible to conduct a wide range of repeatable multivariate simulations for different conditions of protective footwear use (Kuklane et al., 2005; Kuklane and Holmer, 1998; Kuklane, 2009a).

The present work examined toecaps in protective footwear (ankle boots) to evaluate the influence of the toecap material (metal and composite) on the microclimate in the toe region. Changes in the footwear microclimate (temperature and relative humidity of the air) were monitored by means of a thermal foot model.

Table 1
Materials used in the tested protective footwear.

Symbol	Characteristics of the materials	Photograph
A	Toecaps A perforated, vapor-permeable composite toecap with a special arrangement of micropores to ensure natural breathability to the foot. A built-in footwear component designed to protect the toes of the wearer from impacts of an energy level of at least 200 J and compression at a load of at least 15 kN.	
	Footwear Made of high-quality nubuck leather and a liner with a high vapor-permeability coefficient (15 times higher than that required by the relevant standard, according to the manufacturer). This footwear is said to meet both protective and functional requirements and to be "very comfortable."	
B	Toecaps A protective toecap made of steel. A built-in footwear component designed to protect the toes of the wearer from impacts of an energy level of at least 200 J and compression at a load of at least 15 kN.	
	Footwear Made of full-grain leather, the upper is finished with a protective collar filled with latex foam. According to the manufacturer, the footwear meets the requirements of the relevant standards only in terms of protective parameters.	

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