Innovative protective insoles for safety footwear: A balance between protection and comfort

C.S. Ferreira & M.J. Abreu
Departamento de Engenharia Textil, Centro de Ciência e Tecnologia Textil (C2T), Universidade do Minho, Guimarães, Portugal

ABSTRACT: The use of adequate protective footwear and other Personal Protective Equipment (PPE) has become a necessity in view of the number of accidents at work occurred in the past years.

This paper presents a project developed at University of Minho which main goal was the improvement of the existent inserts in terms of comfort. A detailed analysis of the penetration resistant inserts available in the market was made. Chemical, metrological and destructive tests were performed to the normally used materials allowing us to obtain the necessary information about the inserts and select new materials to be applied in this component. The comfort properties (air permeability, mass per unit of area and frictional properties) of the selected materials were tested and compared with the aramid based materials properties to see if the replacement of aramid for any of these materials is profitable in terms of comfort.

1 INTRODUCTION

In the European Union (EU) almost 3 million workers were victims of accidents at work every year, resulting in 500 deaths and an absence from work of approximately 3 days (Communities, 2004). In 2010, nearly 2 634 196 accidents at work occurred in Europe, of which 707 292 affected the lower extremities. These facts led the EU and the member states for the creation of strategies aiming the increase of the use of PPE and consequently the decreasing of the number of accidents at work (Eurostat, 2013).

The safety shoe industry has suffered improvements in order to increase the level of the user's comfort and at the same time decrease the manufacturing costs of the safety shoes and its components. Despite the fact that safety shoes are getting more comfortable, a large number of employees still neglect the use of this kind of protection because they are uncomfortable, have excessive weight, lack of flexibility, models are unsuited to the morphology of some feet, lack of aesthetic/ergonomics or have inadequate ventilation (Goldcher and Ackr, 2005). The legislation define protective footwear as footwear including protective structures (toecaps and penetration resistant inserts) to protect the user from injuries which could arise through accidents. There are three types of protective footwear classified according to the protection that they offer: safety shoes, protection shoes and occupational shoes. The main difference between these three types of shoes is the toecap protection.

In the case of safety shoes, toecaps must resist to a mechanical impact of 200 J, while the impact supported by the protective shoes should be 100 J. In the case of the occupational shoes, toecap protection is not required.

The penetration resistant inserts are one of the most important components of the safety shoes and its main goal is to prevent the penetration of sharp objects. This component suffered a big evolution in the last years. Nowadays, there are mainly available two types of resistant penetration inserts, metallic or made of aramid fibers. The first ones have a thickness of 0.5 mm and due to their high cost production are the most used by the safety shoes producers. The ones made of aramid fiber are very flexible, making the shoe more comfortable, however, their cost is superior to the metallic inserts. Some inserts were patented. In 1991, Kenji Okayasu (Okayasu, 1991) developed a new penetration resistant insert using small metal plates joined together allowing the insert to bend in the front part, the metal plates are involved in an involvole from plastic or rubber in order to prevent the insert damaging in the sole of the shoe. In 2003, Luigi Buttaglia (Buttaglia, 2003) presented an improvement of the simple metallic inserts by applying longitudinal ribs in the back part of the insert. These longitudinal ribs form grooved ribs on the upper surface of the sole that are going to stiffen the area of the arch of the foot. In 2008, Leo Sartor and his colleagues (Sartor et al., 2007) developed an insert with two distinct parts. The front part of the insert is comprised of multiple layers of aramid fiber
confering a good flexibility. The back part of the insert is made of a composite material and acts like a structural element and prevents the heel torsion and therefore heel injuries.

The present work aims the development of a new and innovative penetration resistant insert for safety shoes, regarding the standards, with an improved behavior than the ones already available in the market. For that, we are trying to develop a penetration resistant insert using new and innovative materials that are not being applied in safety footwear. Aiming to improve the comfort of safety footwear, we pretend a decrease of thickness and weight, without sacrificing the physical protection offered by the same. With the decreasing of the insert weight, the shoe weight will also decrease. Moreover, we are considering the incorporation of comfort components on the penetration resistant insert and with that purpose, we compared several new materials with the material already used in the safety footwear industry to see if it replacement would be advantageous in terms of comfort.

2 MATERIALS AND METHODS

2.1 Materials

The materials selected used for this work are based in polypropylene (A), an Ultra-High Molecular Weight Polyethylene (UHMWPE) (B, C, D) and an aramid fibre (E, F, G, H, I, J, K). The UHMWPE based materials B and C are made by the same manufacturer; the main difference between them is their weight. The material based on aramid fibres (K) is from a different manufacturer than the materials E, F, G, H, I and J. The difference between them (E, F, G, H, I and J) is the number of layers.

2.2 Methods

2.2.1 Penetration resistance test

The penetration resistant inserts are footwear components placed in the sole complex in order to provide protection against mechanical penetration. The penetration resistance tests were performed according to the standard EN ISO 12568—"Foot and leg protectors—Requirements and test methods for toecaps and penetration resistant inserts". When tested accorded to the mentioned standard, using a force of over 100 N, the tip of the test nail shall not penetrate through the test piece. A "pass" result requires that the tip of the test nail does not protrude from the rear side of the test piece to be checked by visual, cinematographic or electrical detection. This test was performed for the new materials alone and for the materials combinations.

2.2.2 Comfort tests

2.2.2.1 Air permeability

The air permeability is the ability of a fabric to be crossed by the air through the pores or interstices which rate depends mainly on the size and distribution of pores or interstices between the fibres. The air permeability is determined by measuring the velocity of air flow perpendicularly crossing a specimen under specified conditions (area and pressure). In this work the test has been performed with an area of 20 cm² and a pressure of 200 Pa for non-woven materials. The air permeability test has been carried out following the standard NP EN 9237:1997—"Determination of the air permeability of textiles" with the air permeability tester TEXTEST FX 3300.

2.2.2.2 Mass per unit of area

The mass per unit area has been performed according to the standard NP EN 1217:1999—"Determination of mass per unit area in samples of small dimensions". It was calculated the mass per unit of area of five samples of each material.

2.2.2.3 Frictional properties

The Frictor II method consists of characterizing the coefficients of friction between two flat surfaces based on torque evaluation (Lima et al., 2008). The frictional properties of the materials were tested using the Frictor II. Samples with 84 mm diameter were tested under a conditioned atmosphere.

3 NEW PROTECTIVE INSOLE

The anti-penetration inserts available still have several flaws that undermine the comfort and reliability of safety shoes. The starting point of this study was a detailed analysis of the inserts available in the market, whose results allowed us to understand what the most important characteristics of the inserts are. Chemical, metrological and destructive tests were performed to the normally used materials (steel and aramid) allowing us to acquire the necessary information about the inserts tensile strength, thickness and chemical composition and therefore to select new materials to be applied in this component.

3.1 Penetration tests

Due to properties like flexibility, light weight and good mechanical properties aramid fiber, polypropylene and ultra-high molecular weight polyethylene based materials were selected and tested according to the safety shoes standards. The results of these tests were helpful to see if these materials were suitable options for the new insert. The results

Figure 1. Penetration resistant inserts materials

shown in Figure 1a allow one to see any of these materials option due to their penetra

force combinations of the inserts and their prices and available.

A, E, F, G and H were penetration (Figure 1b).

3.2 Comfort tests

The comfort properties of the new inserts were tested in order to induce better comfort than the property already used in the market. The properties of the new inserts, compared with the property already used for any of the terms of comfort.

3.2.1 Air permeability

The air permeability and the selected materials (Figure 2). Through these tests it is possible to assess the comfort and compared with the penetration resistant inserts. The results show us that the replication available in the market not advantageous for the new insert.

3.2.2 Mass per unit of area

Since the weight of the insert to the user comfort project is the decrease of per unit of area of the insert and compared with the penetration resistant inserts in the market. The results show us that the replication available in the market not advantageous for the new insert.

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The ability of a fabric to breath the pores or interstices on the size and distribution between the fibres is determined by measuring perpendicularly across a defined area (area and test has been performed under a pressure of 200 Pa). The air permeability test following the standard NP EN 12127:1999—per unit area in samples was calculated the mass of each material.

None of the materials were tested with 84 mm conditioned atmosphere.

The tests available still have the comfort and his study was a detailed available in the market, to understand what the nature of the inserts are. Destructive tests were used materials (steel) and require the necessary informative strength, thickness and therefore to select in this component.

Figure 1. Penetration resistance of the selected materials. (a) selected materials, (b) combinations of the selected materials.

Shown in Figure 1a allowed us to conclude that the use of any of these materials alone would not be an option due to their penetration resistance forces, hence combinations of these materials according to their prices and availability were made. Materials A, E, F, G and H were combined and tested to penetration (Figure 1b).

3.2 Comfort tests

The comfort properties of the selected materials were tested in order to find a new material that induces better comfort than the standard material. The properties of the new materials were compared with the properties of the aramid material already used in the market to see if the replacement of aramid for any of these materials is profitable in terms of comfort.

3.2.1 Air permeability

The air permeability of the present materials used and the selected materials were compared (Figure 2). Through the values presented in Figure 2 it is possible to assume that only the replacement of the existing aramid insule with material A is not advantageous for the foot breathability.

3.2.2 Mass per unit of area

Since the weight of the shoes is an important factor to user comfort and one of the goals of this project is the decrease of the shoe weight, the mass per unit area of the new materials was tested and compared with the materials normally used in penetration resistant inserts (Figure 3). The results show us that the replacement of the traditional inserts available in the market for inserts made of any of the new materials would be advantageous in terms of weight.

3.2.3 Frictional properties

The frictional properties of the materials were tested in the Frictorq II. This equipment measures the kinetic or dynamical coefficient of friction between the surface of the sample and the standard metal surface contact element. A relation between the friction coefficient and how soft the material is can
be achieved testing the materials by this method. The results can be seen in Figure 4. The materials with higher friction coefficient are the aramid. Therefore, it can be said that the replacement of the aramid for any of the new materials would be advantageous once they all are softer to the user touch and consequently more comfortable.

4 CONCLUSIONS

The main goal of this work was the increase of comfort and safety of the existing safety footwear. Initially, an analysis of this type of footwear and of the penetration resistant inserts was made. This analysis allowed concluding that there are some failures that could be solved if this component was more comfortable and lightweight, but at the same time more resistant. With the selected innovative materials based in polypropylene, in ultra-high molecular weight polyethylene and in aramid fibre, a new insert with increased comfort and lower thickness and weight can be made. Despite the increase of the comfort of the new resistant penetration insert, the safety and reliability of safety shoes would not be neglected.

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REFERENCES


