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CONSIDERATIONS ON THE COMPRESSIVE BEHAVIOR OF FOOTWEAR PERSONAL PROTECTIVE EQUIPMENT

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Abstract: *The manufacture of safety footwear is subject to a number of mandatory regulations to ensure safety during use. As protective footwear has evolved, a number of tests have been required to ensure that the product fully protects the individual, as required by ergonomic standards (EN ISO 20344). In all workplaces, accidents caused by heavy or massive objects are common for a variety of reasons. In this study, compression tests have been performed on personal protective footwear, including other parameters not included in the testing standards for this type of footwear, such as time and temperature.*
Keywords: *protective footwear, compression, health and safety, standardization, PPE.*

1. INTRODUCTION

Industrial activities are often related to negative external influences, so workers need suitable personal protective equipment (PPE). Protective footwear plays an important role in providing protection.

The most common protective footwear range provides protection against mechanical loading during movement and mechanical influences such as: perforation, cuts, abrasion, falls from heavy objects, pressure from massive loads, vibration, etc.

Personal protective footwear is usually a boot, shoe or boot made of synthetic or natural leather with a durable rubber or moulded polymer sole. The protective elements are made of metal or plastic with a maximum impact strength of 200 J. In addition, this type of protective footwear is reinforced at the ankle and heel.

Current standards require the following aspects to be considered when testing footwear:

- specific ergonomic characteristics;
- determination of the grip force between the upper and the outer sole and between the sole and the mid-sole;
- determination of the internal length of the toe cap;
- shock resistance assessment;
- compressive strength testing;
- conformity assessment of insert dimensions and sole puncture resistance;
- perforation resistance of footwear with non-metallic anti-perforation inserts;
- shock resistance of metatarsal protection device, etc.

The objective of this study was to conduct compression tests for individual protective footwear, with consideration given to additional parameters that have not been incorporated within the prevailing testing standards for this category of footwear. These additional parameters included the holding time and temperatures.

2. MATERIALS AND METHODS

The experimental procedures were conducted within the laboratory, using the technical equipment provided, and the footwear was subjected to compression tests with the same force of 15 kN (1529.57 kg), at different holding times and temperatures.

The equipment utilised for the execution of the tests comprised the following devices: a hydraulic press (Fig. 1), a Furno 750 hot air blower, a DT-838 digital multimeter, a carpet freeze spray for cooling purposes, and an infrared thermal camera, the Flir FLIR-T62101 model.

Fig. 1. General view of the deformation force measurement installation: 1 - press; 2 - hydraulic unit; 3 - displacement transducer; 4 - deformation device; 5 - load cell; 6 - notebook; 7 - Traveller 1 system [1]

The experimental procedure involved the conducting of tests on two individual pairs of protective footwear, categorized as S1. The first pair was characterized by an injected sole composed of polyurethane (PU), which possesses the following properties: monodensity, antistatic, anti-slip, abrasion and hydrocarbon resistance. The sole is covered with non-woven polyamide fibre gill, caulked with polyester fibre fabric, and is antistatic. The lining is made of perforated textile, which is abrasion resistant to ensure foot aeration. The metal toe-cap is 200J shock and compression resistant. The footwear is fastened by means of metal ring-type fasteners and has a reinforced front in pigmented bovine leather. The basic type sole complies with standard EN ISO 20345 [2], being of category S1 SRA.

The second pair of individual protective footwear was of the protective footwear type, with uppers made of pressed natural cowhide leather, lining made of non-woven textile, metal safety bulb, resistant to 200 J mechanical shock, fastening system by stringing through reinforced perforations with anti-corrosion protected staples, top of the boot made of fabric knitted with spongy material, non-woven, stiffened. The upper edge of the boot is designed to cushion the foot and provide comfort, with a leather substitute lining and a spongy interior. The sole of the protective boot is injected with double density PU.

2.1 Tests and results

The experimental procedure involved the performance of compression tests on two types of footwear-type PPE that had been standardised in accordance with SR EN 20345. The testing equipment used was a 750 kN hydraulic press (Hidramold) with a force of 15 kN (1529.57 kg), in order to comply with SR EN 20344 - Personal Protective Equipment. The test methods for footwear [3] were conducted at different temperatures in order to test the footwear also under other aspects not mentioned in this standard, namely at ambient temperature, at high temperature reaching the value of 50 °C in the toe cap area and at low temperature reaching the value of -36 °C in the toe cap area, for different durations. The initial test was conducted at ambient temperature for approximately five minutes, while the subsequent two tests were performed at high and low temperatures for approximately three minutes.

a) Compression resistance testing of footwear at room temperature

The compression test of the toe cap area was performed to determine its ability to withstand a prolonged period of time (5 minutes) at an ambient temperature of 24.2°C (Fig. 2. and Fig. 3.).

In the toe cap area, the shoe is compressed between two plates at a constant speed and a predetermined force of 15 kN. The difference between the initial height of the top of the shoe and the final height is then measured. The test is performed slowly, with a constant advance, and then maintaining the previously specified time of five minutes. The onset of destruction of the sole is observed after approximately 70 seconds, and the destruction (i.e. severing of the sole in the area of the lower contour of the toe cap) occurs after approximately 220 seconds, as shown in Fig. 4 and Fig. 5.

Subsequent to the application of compression, a difference of 6.02 mm was found in the initial height of the footwear in the area of the toe cap.

b) Compressive strength testing of footwear at elevated temperature

The second experiment involved conducting a compression test on the shoe toe cap, but for a shorter duration of three minutes.

Fig. 2. Footwear during compression

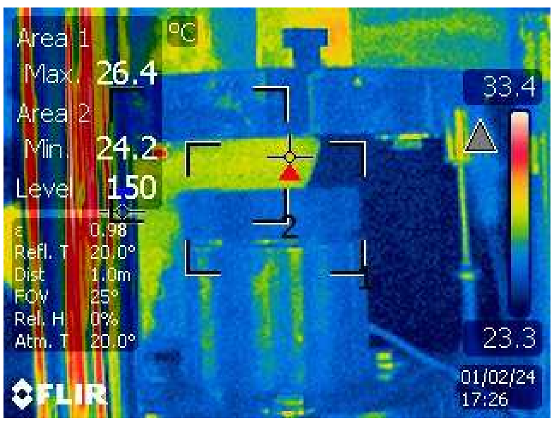

Fig.3. Infrared thermal image (determining the maximum temperature reached by the footwear during the compression test)

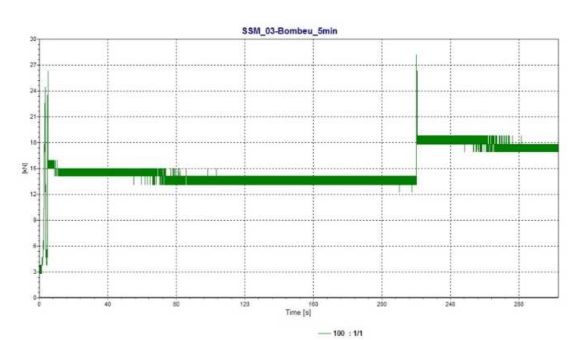

Fig. 4. Time-force graph for ambient temperature compression test
(F max is 15kN, time 5 min)

This test was conducted at an elevated temperature of approximately 50°C, which is higher than the ambient temperature.

The reasons for changing the temperature

Fig. 5. Severed sole of the shoe after compression test

parameter were that the literature and the relevant standard for testing methods for footwear (SR EN 20344) did not specify the conditions under which footwear type PPE should withstand compression with a load of up to 15 kN under different temperature or time conditions.

The footwear was compressed between two plates at a constant rate and a predetermined force of 15 kN for 3 minutes, with the temperature of the footwear in the toe cap area at 50°C (Fig. 6, Fig. 7.).

Fig. 6. Footwear during compression

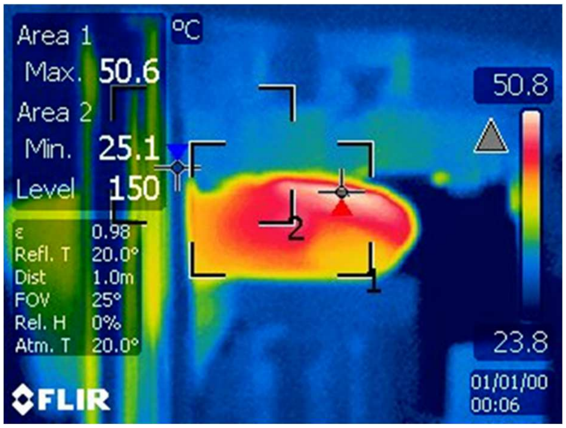

Fig. 7. Infrared thermal image (determining the maximum temperature reached by the footwear during the compression test)

As illustrated in Fig. 8, the time/force graph of the compression test demonstrates a deformation of the sole within the initial 20 seconds. Subsequent to 150 seconds, a more pronounced alteration in the sole deformation of the shoe is observed (Fig. 8).

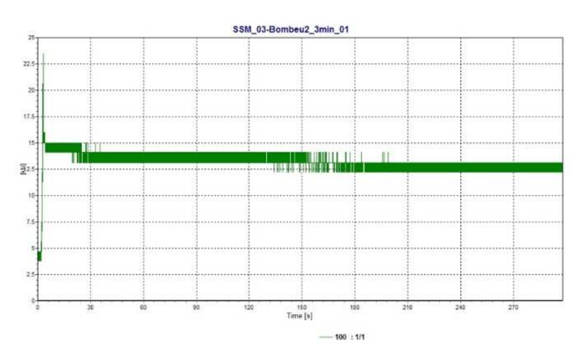

Fig. 8. Time-force graph for the compression test at the maximum of 50°C reached (F max is 15kN, for 3 min)

Furthermore, a difference of 2.34 mm was found between the initial height of the footwear in the toe cap area and the final height of the footwear, without cutting the sole, but with visible deformation due to the high temperature.

c) Compression strength testing of footwear at low temperature

The following test was conducted in order to ascertain the compression strength of the shoe toe cap at -36 °C over a period of three minutes (Fig. 9 and Fig. 10).

As illustrated by the time-force graph of the compression test (Fig. 11), deformations (following deviations from linearity) are observed in the sole or toe cap area after the first 10 seconds, then after 50 seconds and a final change after 120 seconds under a load of 15 kN.

Fig. 9. Footwear during compression

Fig. 10. Infrared thermal image (determining the minimum temperature reached by the footwear during the compression test)

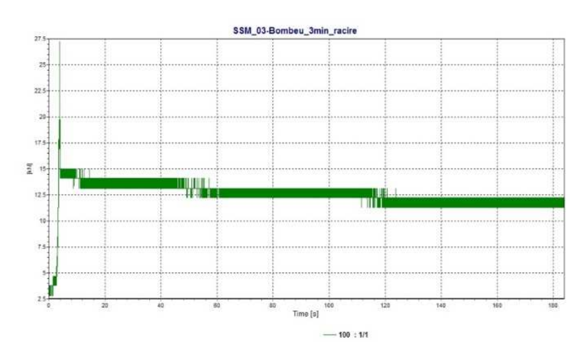

Fig. 11. Time-force graph for compression test at -36 °C (F max. is 15kN for 3 min)

It has been observed that there was a difference between the initial height of the shoe in the area of the toe cap and the final height of 9.58 mm, as well as destruction of the sole in the area of the toe cap (Fig. 12).

Fig. 12. The sole of the footwear after compression test for 3 min at a force of 15 kN at -36 °C

3. CONCLUSION

In accordance with the provisions stipulated within SR EN 20344 *Personal protective equipment. Test methods for footwear, compression testing of footwear*, the compression test of footwear is a method of assessing the load-bearing capacity of the equipment. Test methods for footwear, the compression test of footwear brings into question only the parameter relating to the load to which the PPE is subjected, namely 15 kN.

It is imperative to consider that, irrespective of the nature or the workload associated with the task, a wide range of factors can affect the well-being of the worker, leading to events that may affect their physical integrity. In this paper, the authors have included other parameters in the compression test, i.e. temperature and time.

The tests were performed on two types of footwear PPE, complying with the requirements of SR EN 20345, to which a load of 15 kN was applied using a 750 kN hydraulic press (Hidramold), at three different temperatures: ambient (24°C), high (50°C) and low (-36°C), for different periods of time, the first test for 5 minutes and the following two for 3 minutes each.

The initial compression test was conducted on the SR EN 20345, S1 SRC type certified protective footwear, at an approximate temperature of 24 °C for a duration of 5 minutes and 20 seconds. The deformation process was initiated, resulting in a difference of 6.02 mm between the sole and the sole-toe cap assembly, and a perforated (cut) sole in the area of the lower contour of the sole-toe cap.

The second compression test was performed on the SR EN 20345, S1 SRA-approved type of footwear, at a temperature of approximately 50°C. After 30 seconds of compression, deformation was observed, with a difference of 2.34 mm between the sole and the toe cap assembly, and a deformed but not cut sole in the area of the lower contour of the toe cap.

The third compression test was conducted on the SR EN 20345, S1 SRC type certified footwear, at a temperature of approximately -36°C, where deformation began after 10 seconds. The measurements revealed a difference in the size of the sole-toe cap assembly of 9.58 mm and a partially perforated (sectioned) sole on the lower contour of the toe cap.

The following conclusions can be drawn from the study and the experimental results obtained:

1. the experimental results have shown that, in the case of protective footwear with a toe cap, the compressive strength of the toe cap over a long period of time does not guarantee the existence of at least equal resistance of the sole, which may have consequences for the integrity of the worker if the intervention to remove the weight exceeds a certain, relatively short time interval;

2. the content of the test standards, in that they do not require a compression test of the entire sole-toe cap assembly to determine resistance over a certain time interval, allows the marketing of individual protective equipment such as footwear with a protective toe cap. The absence of a compression test for the sole-toe cap assembly within the test standards, which is crucial for determining the resistance over a specified time interval, enables the release of individual protective equipment such as footwear with a protective toe cap that, in its overall state, cannot provide sufficient resistance until the compression elements have been removed;

3. the development of a standardised framework for testing the compressive strength of the sole/toe cap assembly of protective footwear at different temperatures would allow an accurate selection of PPE, considering some situations in which workers may engage in activities during the warm season, e.g. activities on pavement surfaces in summer, in relation to the protective capacity of footwear under compressive loads, which may lead to accidents when there is an interaction between a final cause specific to production facilities or the working environment and a cause specific to the worker [4].

4. REFERENCES

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Considerații asupra modului de comportare la compresiune al echipamentelor individuale de protecție de tip încălțăminte

La fabricarea încălțămintei de protecție se ține cont de un set de reguli obligatorii, pentru a asigura cerințele de siguranță în utilizare. Odată cu evoluția încălțămintei de protecție, au fost necesare o multitudine de testări pentru a asigura că acest produs protejează în totalitate utilizatorul, stipulate în standardele ergonomice (EN ISO 20344). La toate locurile de muncă, accidentele datorate corpurilor grele sau voluminoase se produc frecvent din diverse cauze. În acest studiu, au fost realizate încercări de compresiune pentru încălțămintea individuală de protecție luând în considerare și alți parametri care nu au fost luați în considerație în standardele de testare a acestui tip de încălțăminte, respective timpul de menținere și temperature.

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