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Ceramic Floor Slipperiness Classification – A new approach for assessing slip resistance of ceramic tiles

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HIGHLIGHTS

- Importance of slip resistance tests was discussed.
- Slipping properties of 28 ceramic tiles with different surface texture were assessed.
- Slipperiness values obtained by various standardized test methods do not correlate.
- A solution for representing slipperiness interpreted in a combined form was introduced.
- A novel methodology for the classification of slip resistance of ceramic tiles was developed.

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ABSTRACT

Regarding the application of ceramic tiles there is a great importance of defining and measuring slip resistance of floor coverings. The objective of this study was to determine slipperiness of ceramic tiles and to make a comparative analysis on the different measurement methods. Laboratory slip resistance tests were conducted on 28 different ceramic tiles by three different methods providing the average angle of inclination, the pendulum test value and the coefficient of friction. By comparing the obtained test results, relationship between individual methods was determined. Based on this information Ceramic Floor Slipperiness Classification (CFSC), a new system was prepared concerning the selection and application of tiles.

1. Introduction

Floor covering is responsible for ensuring the mechanical properties and the quality of flooring regarding its function and application, so it is essential to design it for its purpose. Stresses must be carefully predetermined and evaluated as they constitute performance requirements for building materials and are fundamental to the design of floors [1]. Obviously, from general criteria described in Construction Products Regulation (EU) No. 305/2011 (CPR) [2], determination of slip resistance especially plays a major role in fulfilling the regulation of safety and accessibility in use.

Previous studies confirm that measuring slipperiness is a complicated problem, not only because slip resistance is related to friction [3,4] occurring at the surface/shoe interface [5], but surface roughness is also an important factor [6,7] in determining the most appropriate finish for use in various environments and activities. This property is sometimes missing from manufacturers' declaration of performance, however this information is necessary for choosing a product for a specific application.

Slip resistance is one of the major characteristics prescribed by EN 14411 [8] for the purpose of CE marking of ceramic tiles [9,10]. On the international level requirements and regulations of slip resistance have been rather diverse. Unification is challenging, because each country established and introduced its own test methods and guidelines. The following can be highlighted:

- *BGR 181 (2003)* [11] *and GUV-I 8527 (2010)* [12] – Germany – ramp test,
- *HSE Guidelines* – UK – pendulum test,
- *DPR n. 236. (1989)* Decree – Italy – floor friction test,

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- *SA HB 198 (2014)* [13] Standard – Australia – pendulum test, ramp test and floor friction test,
- *Americans with Disabilities Act (1990)* – USA – floor friction test,
- *253/1997. (XII.20.) Government Decree (OTÉK)* – Hungary – no test method determined. This requires that floors must not be slippery, but yet there is no clear instruction or guide for determining slipperiness of ceramic tiles in quantitative terms.

The article presents a new classification system evaluating slipperiness of ceramic tiles as the mostly chosen material for floor covering solution in practice.

1.1. Importance of slip resistance of ceramic tiling

Floor coverings made of ceramic tiles are subjected to various stresses for both internal and external usage. For assessing slip resistance there is no requirement in EN 14411 [8]. At the same time, according to this standard, tiles intended to use on floors need to be tested. CEN/TS 16165 [14] technical specification for determining slip resistance of pedestrian surfaces can be an aid for the evaluation. It contains three test methods (ramp test, pendulum friction test and tribometer test) for expressing the friction of materials in contact. In previous studies the interaction between floor surface and shoe [15] or barefoot [16], the occurence of accident and its dynamics [17,18], modelling of quantification of pedestrian slip resistance [19–21] were analysed. It was apparent that slipperiness has not been considered to be an important property, however in some areas, there is an increased risk of slipping due to interact with slippery materials [22]. Water, oil, grease, soap, dust, sand, etc. are general contaminants that can cause accidents [23]. Taking into account the presence of a lubricant or contaminant material on the surface, which can cause the test persons to lose their footing, loss of traction can be predicted.

2. Experimental

2.1. Materials

In the research 28 different types of dry-pressed ceramic tiles were selected. This production method is more productive and economical than extrusion, so today the majority of the world's tiles are produced by dry pressing technology. Fig. 1 shows the images of tested ceramic tiles. There were 14 – 14 types of glazed (G) and unglazed (UG) tile groups, chosen from all over the world to show diversity not only in origin, but in material, in texture, thus in the behavior also (Table 1). Illustrating the variety in surface texture roughness was determined for each product using 2 parameters: arithmetical mean deviation (Ra) and the maximum height of the assessed profile (Rz). For the present work sampling was carried out from 5 boxes (cca. 30 pieces/type) in order to represent potential alteration within each type.

2.2. Testing methods and devices of slip resistance

There are numerous test methods, and each has its own benefits [24,25]. One can state that all are based on different principles, so values obtained by using various test methods do not correlate with each other. Therefore the use of an individual test result in the assessment process of slip resistance may not give a proper understanding of the characteristics of the surface [26].

In this research multiple testing was performed to provide more precise approach of slipping properties. For determining results obtained by different procedure we applied the following methods presented in details by Terjék [27]:

- Ramp test – angle of inclination (α).
- Pendulum friction test – Pendulum Test Value (PTV).
- Floor friction test – coefficient of friction (μ).

According to CEN/TS 16165 [14] these methods are the most commonly used for determination of slip resistance, however measuring devices are operated differently and provide unlike units.

Ramp test is used to determine the angle of an inclined plane on which a test person moves forwards and backwards until the safe limit of walking is reached and a slip occurs. When tested with barefoot the wetting agents are water and NaLS solution. If the test person wears shoes, the tested surface is coated with oil as a contaminant.

During the pendulum friction test the slider assembly moves across the test surface measuring the loss of energy. The reduction in length of the swing represents the friction between slider and test surface. This method can be implemented with a test surface in dry condition or contaminated with water.

Floor friction test measuring directly the coefficient of friction is based on using a tribometer. During movement quotient of the horizontal frictional force and the vertically acting force between the slider and the surface can be detected both in dry and wet conditions.

3. Results and discussion

3.1. Laboratory test results

In this study we decided to investigate the correlation between the above mentioned, mostly applied slip resistance methods focusing on the difference in measures. For this reason the three relevant tests have been performed on ceramic tiles characterized by different surface texture (see Fig. 1) to assess the interaction of slipperiness in different circumstances. In Table 2 average values of slip resistance measurements are presented.

3.2. Correlation between various slip resistance tests

Friction can be measured according to different principles and can be represented as force, angle or energy loss [28]. For making comparison of the applied methods and the obtained results, coefficient of friction is the linkage. The angle of inclination of ramp tests by Eq. (1) [28] and PTV by Eq. (2) [29] can be represented in the form of the coefficient of friction:

$$\mu = \mathrm{tg}\alpha \tag{1}$$

$$\mu = (110/\mathrm{PTV} - 1/3)^{-1} \tag{2}$$

However the principles of friction measuring devices are not the same, they all provide information on the slip-resistant ability of a surface even though the moving body can be a slider or a person. Human-centred measurements thus provide an additional assessment to mechanical friction-based test methods. Understanding of friction as a complex interaction is based on the law of motion using vector analysis. Fig. 2 shows the principle of frictional measurement and calculation of friction.

By applying results of previous studies and guidelines, relationship between different methods was evaluated showing the alteration that may lead to misrepresentation of the slip resistance ability of a ceramic tile or other flooring material. Operating conditions of the methods are very diverse, thus strongly influence test results. Furthermore, the graphical representation (Fig. 3) also indicates that classification of test procedures do not correspond well.

The rating of ramp test results is relevant just above a given angle of inclination (12°). Values not exceeding this limit belong to the non-qualified range. From this aspect the research shows that measurements on surface wetted with NaLS solution give unsatisfactory results.

Statistical analysis was performed with NCSS 11 software. Based on the analysis of variance (ANOVA) using the mean values of the results, it was found that there is a poor correlation. Relationship was analyzed between test results measured by the 3 methods and the calculated coefficient of friction by using Eqs. (1) and (2). A comparison was made between classification based on measured values and classification based on converted values (measured coefficient of friction was converted into angle of inclination and PTV), and the results show alteration in ranking. As it