Slipping properties of ceramic tiles / Quantification of slip resistance

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Abstract. Regarding the research and application of ceramic tiles there is a great importance of defining precisely the interaction and friction between surfaces. Measuring slip resistance of floor coverings is a complex problem; slipperiness is always interpreted relatively. In the lack of a consistent and clear EU standard, it is practical to use more method in combination. It is necessary to examine the structure of materials in order to get adequate correlation. That is why measuring techniques of surface roughness, an important contributor to slip resistance and cleaning, is fundamental in the research. By comparing the obtained test results, relationship between individual methods of analysis and values may be determined and based on these information recommendations shall be prepared concerning the selection and application of tiles.

1. Floor covering
Floor covering is responsible for ensuring the quality, properties and aesthetic appearance of flooring regarding its intended use. Some of the main requirements are sufficient strength, resistance to abrasion, volume stability, sufficient flexibility, walking comfort, slip resistance, cleanability and fire resistance, etc.

A wide range of products is available on the market; products with different appearance (color, surface texture, decoration, etc.), different technical characteristics associated with different expected performance levels. One has to consider all the tile characteristics that are relevant to a specific application.

The selection of materials is a fundamental step in the design process of flooring, since it can significantly influence the achievement of a satisfactory compliance with the essential requirements of Construction Products Regulation (EU) No 305/2011 (CPR):

- Mechanical resistance and stability
- Safety in case of fire
- Hygiene, health and the environment
- Safety and accessibility in use
- Protection against noise
- Energy economy and heat retention
- Sustainable use of natural resources
Construction works as a whole and in their separate parts must be fit for their intended use, taking into account in particular the health and safety of persons involved throughout the life cycle of the works. Subject to normal maintenance, construction works must satisfy these basic requirements for construction works for an economically reasonable working life. The construction works must be designed and built in such a way that they do not present unacceptable risks of accidents or damage in service or in operation such as slipping, falling, collision, burns, electrocution, injury from explosion and burglaries. In particular, construction works must be designed and built taking into consideration accessibility and use for disabled persons [1].

Among the 7 general criteria my study deals with safety and accessibility in use, especially the slip resistance of ceramic floorings.

2. Ceramic tiling
Ceramic tiles belong to the third possibility of the declaration of conformity; basically initial type testing and factory production control is done by the manufacturer. Since the publication of harmonized standard EN 14411 for ceramic tiles, number of expertises has increased especially in the issue of slip resistance which is the most controversial feature of these products. There is no requirement, but according to this standard tiles intended to use on floors need to be tested.

In Hungary there is no clear instruction, guide or unified testing method for determining slipperiness of ceramic tiles. EN ISO 10545-17 was never published, but it would have been an aid for testing, because it contained three suitable test methods.

3. Importance of slip resistance
Slip resistance of ceramic tiling is an existing and important problem. The risk of slipping depends not only on choice and performance of tiles, but also human and environmental factors. This property is often incomplete or inaccurate, the question of it along with the knowledge of cleanability appear in all part of life. It was apparent that many suppliers/architects did not consider slip resistance to be an important property, however in some workplaces, there is an increased risk of slipping due to work with slippery materials. Accidents are affected greatly by the surface structure of floors and possible contamination; water, oil, grease, soap, dust and sand, etc. It can be stated that the multiple testing of properties resulting from surface patterns, fixing, maintenance and cleaning is essential.

4. Frictional mechanism, slipperiness
Friction is the force needed to pull a body across a surface. It resists the relative motion of solid surfaces in contact. Coulomb friction is governed by the equation: \( F_s \leq \mu N \), where 
\( N \), normal force 
\( \mu \), coefficient of friction 

This approximation provides a threshold value for this force. The coefficient of friction depends only on the material, especially on the roughness of the surface (figure 1). It is a value which describes the ratio of the force of friction between two bodies and the force pressing them together.

![Figure 1. Contact area between materials.](image)
5. Testing methods and devices of slip resistance

In order to determine slipperiness, it is necessary that these values can be measured. The purpose of using the appropriate device is to try to imitate walking, nevertheless to ensure repeatability. In the last 50 years, many equipments and methods were developed for use in laboratory and also portable ones.

Picking a favorite test method to assess slip resistance and using a single result to select a product is no longer appropriate [2].

I do research on a composite solution, where multiple testing of slipping properties can provide more precise definition of usability. It is advised to use more methods in combination, rather than to rely on a single result. For determining results obtained by different procedure our laboratory applied the following methods:

- Inclined ramp test
- Skid-resistance test (SRT)
- Floor friction test

5.1. Inclined ramp test

The classical method for determining the static coefficient of friction is the inclined plane shown in figure 2. The so-called ramp test based on methods of DIN 51097 and DIN 51130 is widely recognized. These tests involve a subject walking back and forth on a contaminated test panel. The angle of inclination of the panel is gradually increased until the test subject slips. The average angle at which slip occurs is compared to a classification range. This angle is a measure for the coefficient of friction.

Testing on oily surface, the scale runs from R9 to R13. In Germany BGR 181 regulation introduces requirements for different uses in this case.

When surface is contaminated with water, scale runs from A to C. GUV-I8527 (former GUV 26.17) gives precise instructions for areas where people walk barefoot, such as swimming pools and spas.

![Figure 2. Inclined ramp.](image)

5.2. Skid-resistance test

Skid-resistance tester (SRT) illustrated in figure 3 was developed to provide the skid resistance of wet road surfaces. It operates by the principle of the Charpy pendulum. On the swinging arm the slider is allowed to fall from a certain angle, and it rubs against the surface that is being tested. The measured value is proportional to the absorbed potential energy of the slider.

The pendulum tester has advantage in that it can give reliable results in both wet and dry conditions and its portability means it can be used on site as well as in the laboratory. This proves that this method is used in several cases for stones and concrete products.
5.3. Floor friction test

Floor Slide Control 2000 Print (figure 4) is an example of equipments used for floor friction test. It travels across the surface and simulates foot traffic on the floor. It runs with its own drive, pulls the measuring glider and by pushing a button displays the calculated coefficient of friction. The measured values can be printed out.

![Figure 3. Skid Resistance Tester.](image)

![Figure 4. FSC 2000 Print (a) and its gliders (b).](image)

6. Assessment of testing methods

Based on the evaluation of test methods it is very difficult to draw direct comparison and convert one test result to another. Furthermore it is important that the acceptance of any method for a specific application should be based on subjective experience. The purpose of slip resistance testing should be to define the minimum result that is likely to be obtained [3]. In my research principles of available previous studies, regulations and international standards were used. By adapting their classifications presented in table 1-4 and taking into account test results of products distributed in Hungary the system of evaluation has been clarified and will be completed with the combined results of all three methods in the future.

| Classification | Average angle of inclination | Coefficient of friction ($\mu$) |
|----------------|-----------------------------|--------------------------------|
| R9             | 6°-10°                      | 0,00-0,17                      |
| R10            | 11°-19°                     | 0,18-0,34                      |
| R11            | 20°-27°                     | 0,35-0,50                      |
| R12            | 28°-35°                     | 0,51-0,70                      |
| R13            | 36°-                         | 0,71-1,00                      |
Table 2. Inclined ramp test (wet).

| Classification | Average angle of inclination | Coefficient of friction (μ) |
|----------------|-------------------------------|-----------------------------|
| A              | 12°-17°                       | 0,21-0,31                   |
| B              | 18°-23°                       | 0,32-0,43                   |
| C              | 24°-                           | 0,44-1,00                   |

Table 3. Skid resistance test (SRT).

| Classification      | Skid-resistance value |
|---------------------|-----------------------|
| T1 (very bad)       | 0-24                  |
| T2 (bad)            | 25-34                 |
| T3 (average)        | 35-44                 |
| T4 (good)           | 45-54                 |
| T5 (very good)      | 55-150                |

Table 4. Floor friction test.

| Classification      | Coefficient of friction (μ) |
|---------------------|-----------------------------|
| M1 (very bad)       | 0,10-0,21                   |
| M2 (bad)            | 0,22-0,29                   |
| M3 (average)        | 0,30-0,42                   |
| M4 (good)           | 0,43-0,63                   |
| M5 (very good)      | 0,64-1,00                   |

7. Cleanability
Risk of slipping on flooring is mostly affected by the presence of contamination. Slip resistance of ceramic tiling can change with use. Different material behave differently against various chemicals, they also differ in tendency of staining and cleanability.

The required or specified slip resistance can be maintained by frequent effective cleaning with appropriate detergent and cleaning tools. The question of resistance to chemicals and staining regarding ceramic tiling is necessary, so the surfaces of these tiles need to be examined in order to get adequate correlation.

8. Surface roughness
Surface roughness, an important contributor to slip resistance and cleaning, is significant due to the fact that production technology defines the surface quality of a flooring material. Roughness is a measure of the texture of a surface, thus it is quantified by the vertical deviations of a real surface from its ideal form.

During measurement a diamond stylus (figure 5) with a very small (scale of μm) tip radius is moved in contact with a sample for a specified distance and contact force. It scans unevenness of surface and a filtered roughness profile is used for evaluation.

Figure 5. Stylus of surface roughness-meter.
The remaining profile is partitioned into adjacent segments, where height is assumed to be positive in the up direction. The value of surface roughness depends on the scale of measurement [4]. There are many different roughness parameters in use for describing the surface, each of them is calculated using a formula. Most common parameters are the arithmetical mean deviation (R_a) and the maximum height of the assessed profile (R_z). By comparing the obtained test results, relationship between the two parameters can be determined.

A profilometrous surface roughness-meter, Surftest SJ-301 can measure small surface variations in vertical stylus displacement as a function of position. The approach is to measure and analyze the surface texture in order to be able to understand how the texture is influenced by its history (manufacture, wear) and how it influences its behavior (adhesion, friction). Surface roughness measurements provide an additional indication of slip resistance potential [5].

9. Summary
Slip resistance of a ceramic floor in service depends on the characteristics of its surface and these may change over the lifetime. Tendency of slipperiness and efficiency of applicable cleaning detergent can be determined accurately by quantification and consideration of roughness.

Polished surface of ceramic tiles has low coefficient of friction, therefore dangerous in term of slip resistance. Roughening of a surface has positive effect on slip resistance, but at the same time prevents the easy removal of dirt. For ceramic tiles to give satisfactory service, it is necessary to be selected and installed competently, and to receive appropriate initial treatment, protection and maintenance.

10. Conclusions
There are no official requirements covering the slip resistance of floors in Hungary, but an acceptable safety shall be pursued and achieved, therefore authorities have to specify requirements for different usage. This does not mean that from now on many types of tiles shall be forbidden to be installed.

A possible solution will be a development of a useful guideline like Annex N for abrasion resistance in EN 14411. In my research it is not relevant whether an approach is examined to be better than the other, but with the knowledge of collective test results obtained by using available equipments a suitable threshold value shall be determined for a variety of application areas.

In Hungary, as a member of the European Union, CPR for ensuring reliable information on construction products in relation to their performances has already entered into force. The main parts of its substantial Articles shall apply first from 1 July 2013. Where an intended use requires threshold levels on relation to any essential characteristic to be fulfilled by construction products in Member States, those levels should be established in the harmonized technical specifications.

As far as I am concerned determining if a tile is safe or not regarding the influence of its surface is not adequate. Placing more emphasis on the quantification of slip resistance would allow customers to make comparisons and help them to select the most appropriate product for their needs. Manufacturers shall take responsibility for the conformity of their product with its declared performance, therefore providing them with a recommendation can help reducing the risk of slipping.

References
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