THE CLASSIFICATION OF HARD FLOOR COVERINGS ACCORDING TO SLIP RISK: A NEW APPROACH FOR CERAMIC FLOOR COVERINGS

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ABSTRACT

The European Collective Research Project „Development of Slip resistant Standard Surfaces for a Safer Environment – SlipSTD" [1], performed within the sixth framework programme, aims to reduce the number of slip accidents by advising on surface characteristics for hard floor coverings in internal pedestrian areas when these surfaces are foreseeably contaminated with liquid or solid contaminants. Based upon the slip potential of environment in which they are used the specification and the maintenance of these products is defined. Main floor surface characteristics associated with slip resistant floorings have been defined using 3D optical topography and fundamental knowledge on the influence of surface characteristics on slip properties in various environments of hard floor coverings has been developed. The Publicly Available Specification (SlipSTD PAS), generated in the project, promotes the primary use of topographic measurements as an objective, unbiased and accurate method for establishing the suitability of hard floor coverings (i.e. ceramic tiles and natural stone) floors in terms of slip resistance classification, thus reducing the need for a diversity of slip resistance measurement methods. The underlying research performed is discussed, and the use of the results for a risk assessment-based classification, which considers the likelihood and nature of contamination expected to be found in the pedestrian environment in which the floor covering is to be installed and used, is presented.

1. INTRODUCTION

International research as well as accident statistics [2,3] indicate that the amount of slipping and tripping accidents is significant, the majority occurring on contaminated floors and coverings, and predicted to increase with the aging population. In particular fall-related accidents in residential, publicly accessible, private commercial and work place areas, leading to injury, claims and compensations represent a huge cost for the community, both in monetary value and human suffering. To prevent these accidents a significant amount of effort has already been invested in understanding the causes for such accidents and reducing their incidence and severity [4].

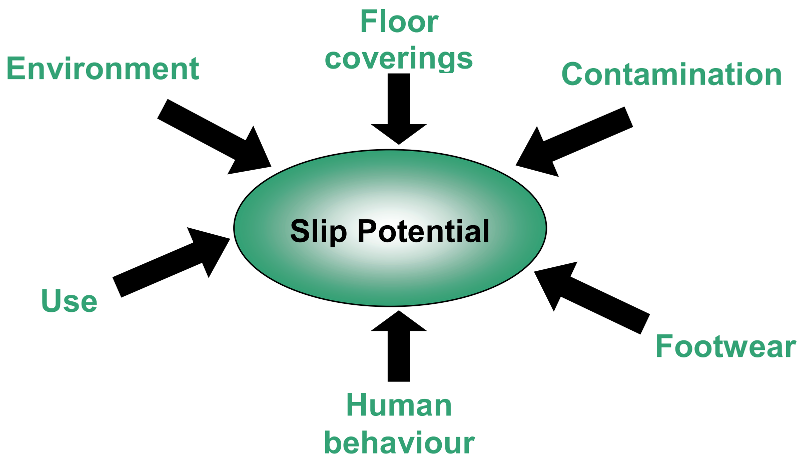


Figure 1. Factors contributing to slip potential (adapted from www.hse.gov.uk).

It is well accepted that several environmental factors (pedestrian surfaces, footwear, contaminants, lighting and signalling) and human factors (biomechanics, neuromuscular control and sensory capabilities), which can only partially be predicted and controlled, contribute to the slip potential of a floor (figure 1). It is widely accepted that floor surface contamination with liquids and solids is the main cause of pedestrian slip accidents. The assessment of these influences is the basis to specify the slip potential, the risk of slipping to occur, and the respective actions to be taken [5-7].

One important aspect that can be regulated and controlled is the slip resistance of the floor covering. Knowledge of the surface parameters influencing the slip resistance will support the choice and use, as well as the development of slip resistant surfaces, so in the end contribute to the reduction of the number of accidents. In this regard, the European SlipSTD Project set out, within an international consortium including tile manufacturers, tile manufacturers associations, architects, Health & Safety associations and leading European Research Centres (figure 2) to better understand the effect of tile surface characteristics on slip resistance by studying these correlations under different contamination situations. The consortium comprises leading experts on ceramic surfaces, tribology, biomechanics, health and safety regulation and production technology. Surface characteristics were evaluated in order to forecast the slip resistance of these floor coverings to be obtained with the prevalent test methods, and to specify minimum surface requirements relating to the expected slip potential under different contamination circumstances. These microstructural aspects were then used to classify hard floor coverings, combined with recommendations for keeping hard floorings uncontaminated, addressing maintenance and cleaning and control measures to be implemented. For this purpose a Publicly Available Specification (SlipSTD PAS) was drafted in the project, promoting the primary use of topographic measurements as an objective, unbiased and accurate method for establishing the suitability of hard floor coverings (i.e. ceramic tiles and natural stone) floors in terms of slip resistance classification.

Another tangible result of the project, which will be discussed in following publications, is the development of standard surfaces, which provide a reliable basis for calibration for different slip testing methods, based upon a specified and reproducible surface setting, with defined slip resistance grades.

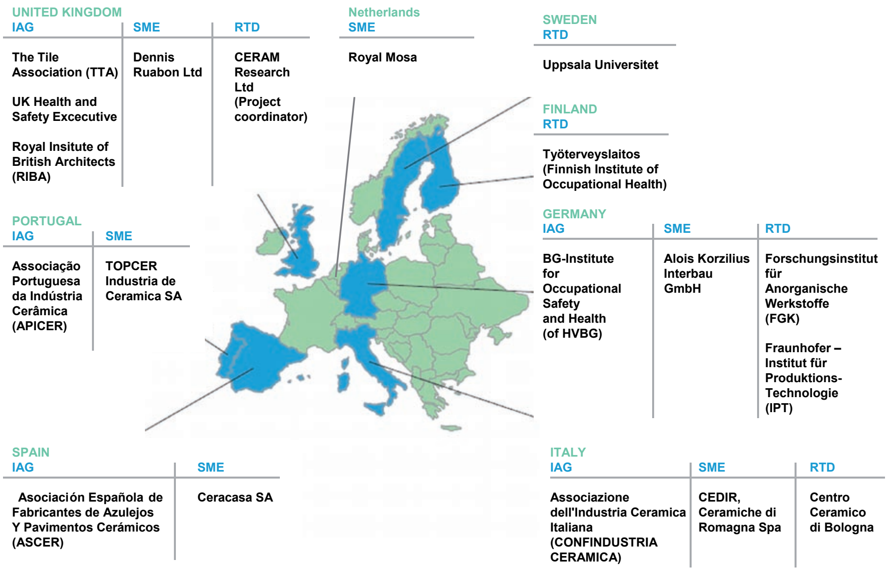


Figure 2. The SlipSTD international consortium Partners (courtesy of CERAM). SME = small & medium sized enterprises, RTD = research and technological development, IAG = Industrial Associations and Groupings.

2. SLIPPERINESS, FRICTION AND SURFACE ROUGHNESS MEASUREMENT

Friction has commonly been adopted as an indicator for floor slipperiness. In the complex system of slipping on a floor, influenced by the sole, the floor and the medium in between (water, contaminants), the surface roughness has been identified to play an important role. Measurement of the coefficient of friction between footwear and floor has been the subject of extensive research [8,9]. Field studies that combine friction, roughness measurement and slipperiness measurement by the prevalent methods however are rare. The available literature indicates that measurement of the floor surface topography may provide a reliable and objective addition to the friction measurement, which is known to give different results with different methods used, due to its dependence on measurement settings, operator influences, test conditions and surface preparation. However, due to the nature of the ceramic surface, special requirements regarding measurement and interpretation have to be met.

Fundamental knowledge on slip resistant surfaces regarding the topography (micro and macro structures or textures) and the relevance of the surface structure in various environments is currently based upon surface measurements using the commonly used 2D tactile testing methods [4,10,11]. One key obstacle currently hindering the implementation of these measurement techniques on ceramic surfaces is the limitation of the tactile method, which is based on dragging a diamond tip over the surface. Due to the large bandwidth of height profiles, ranging from smooth, flat polished tile surfaces to textured and geometrically profiled surfaces with structures up to 1 mm or even higher, edge effects and the possible hooking or even damaging of the needle in the surface rule out the measurement on many of the tile surfaces used. Another difficulty is presented by three-dimensional character of most of the tile surfaces, which are not provided by 2D profile measurements. The currently available equipment for non-contact 3D microscale topography measurement, based upon using spectral shifts and interferences in light reflection by sensors or microscopes, provides the required height range, adjustable lateral resolutions and the capability for three-dimensional mapping of larger, representative surfaces [12].

Various profile-based surface parameters, based upon two-dimensional measurement techniques have been specified and standardized to uniquely describe and identify surfaces. They are commonly used for machined surfaces as performance and quality control criteria. Parameters addressing the amplitude and shape of the surface irregularities, describing the spacing and surface distribution characteristics, as well as combined parameters have been standardised (table 1) [13-17].

Definition of commonly used basic surface parameters			
Ra	Arithmetic average of profile heights/ centre line average	**EN ISO 4287**	**A**
Rq	Root mean square of the profile heights	**EN ISO 4287**	**A**
Rz	Average peak-to-valley height within the sampling length	**EN ISO 4287**	**A**
Rt	Maximum peak-to-valley height within the sampling length	**EN ISO 4287**	**A**
Rp	Maximum height of the profile above the average line within the measurement length	**EN ISO 4287**	**A**
Rv	Maximum depth of the profile below average line within the measurement length	**EN ISO 4287**	**A**
Rsk	Skewness of profile	**EN ISO 4287**	**S**
Rku	Sharpness of the profile	**EN ISO 4287**	**S**
Rk	Kernel or core roughness depth (material ratio curve)	**EN ISO 13565-2**	**C**
Rpk	Reduced peak height (material ratio curve)	**EN ISO 13565-2**	**C**
Rvk	Reduced valley depth (material ratio curve)	**EN ISO 13565-2**	**C**

Table 1. Definition of commonly used basic surface parameters. A = amplitude parameter, S = Shape parameter, H = combined parameter. The parameters are calculated roughness parameters. Similar primary parameters which can be derived from the unfiltered profile, are denoted the indication "P" instead of "R".

The surface parameters are based upon the description up the measured profile of surface irregularities as a spectrum of different wavelengths. The calculation of surface roughness parameters from this profile involves the application of a filtering mechanism, using the so-called cut-off length, a filtering length suppressing surface wavelengths above the specified value: longer cut off lengths include more components of the surface waviness profile, shorter cut off length more components of the surface micro-roughness profile. The adequate settings to address the actually measured profile are standardized for 2D measurements [17]. These parameters are intended as performance indicator for the surface manufacturing process. The description of the surface regarding the functional friction characteristics however requires physical parameters. In this regard primary unfiltered profile parameters had to included in the performed analysis.

The use of the Rz value to indicate and control the behaviour of the ceramic surface in regard to its slip resistance properties, using commercially available 2D micro-roughness meters has already been described [4] as a experience-based practical approach. The Rz parameter can however be influenced by single artefacts (pinholes, pores) not contributing to slip resistance functionality, the effect being even stronger for 2D measurements [13]. In the literature therefore the use of (electron) microscopy to check the validity of these parameter values is advised [18]. The Ra value, averaging the profile, is shown to repress essential surface information: different profile types (with possibly different slip functionality) can be measured with the same Ra [13].

Literature analysis on the use of 2D tactile measured roughness parameters for friction analysis [8,10,19,20,21] confirms however the need for a larger measurement area as well as the use of other parameters (or even combinations) than the commonly used Ra and Rz for ceramic surfaces. Amplitude parameters describing the profile, spacing parameters as well as parameters which are based upon the material ratio curve (table 1) are indicated to have a better potential describing friction characteristics. The fact that most results discussed were derived from smooth tiles (Ra 10 – 20 µm) with slip measurement methods not commonly used for slip resistance classification, illustrates however the limited use for classification purposes.

An important conclusion to be drawn from literature is that an exact specification of the measurement settings, the cut off length and the measurement resolution is a requirement for comparative measurements [18,22] is the basis for any comparative study. The definition of a unambiguous measurement procedure is expected to be even more critical for three-dimensional measurement techniques with a higher complexity; the specification of relevant area-based 3D parameters and the measurement settings are still ongoing [23].

This situation confirms the need investigate a new set of physical three-dimensional parameters to describe the surface, assessed by a measurement method able to operate on the common range of surfaces of ceramic tiles, in relation to the slip resistance functionality, as obtained with the prevalent slip classification methods. The consortium included all relevant expertise to perform this investigation.

3. EXPERIMENTAL METHODOLOGY

The research performed has been based on an inventory of ceramic tile surfaces, characterized using standardized test methods for tiles[1], as well as by prevalent methods for testing slip properties.

As 3D surface measurement method an optical profilometer (FRT MicroProf®), using chromatic length aberration, measuring the shift in the reflected spectrum of a perpendicular beam of light, was used. The equipment is capable of measuring a height range of 3 mm (vertical resolution 3 nm) and a lateral resolution of 2

1. *EN 14411: 2006 „Ceramic Tiles – Definitions, classification, characteristics and marking".*

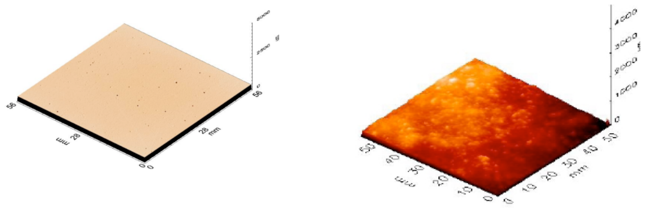
µm, capable of measuring a 300 x 300 mm surface area. With this apparatus 3D measurements were performed, from which 2D profiles could be calculated.

To validate the method an extensive inventory was performed, in comparison with a Mitutoyo Surftest 201 tactile measurement unit (90°, tip radius 5 µm), based upon the use of the 2D measurement settings as described in EN ISO 4288 [13,17]. Using these settings 2D and 3D measurement results for different cut-off length settings[2] and measurement resolutions on ceramic surfaces were compared. The results show that especially the amplitude parameters like Rz show large variations due to the heterogeneous nature of the ceramic surfaces. Significant differences were found in measurement results between the methods even when using moderate lateral resolutions (0,1 mm). Based upon the conclusions of these results, confirmed by microscopical analysis, the use of optical topography for the statistical representation of ceramic surfaces is preferred for the investigation in the project.

Since the standardisation of the 3D measurement procedure is still in progress, the research focussed on developing an adapted measurement procedure with sufficient accuracy and repeatability, which now can be specified according to the EN ISO 4288, using a lateral resolution of 0,1 mm on a total measuring area of 56x56 mm, and a measuring rate of 30 to 100 Hz using a 3rd degree polynomial correction for planarity deviations. For the correlation analysis primary unfiltered data, as well as roughness parameter using the cut-off length filtering according to EN ISO 4288 were used.

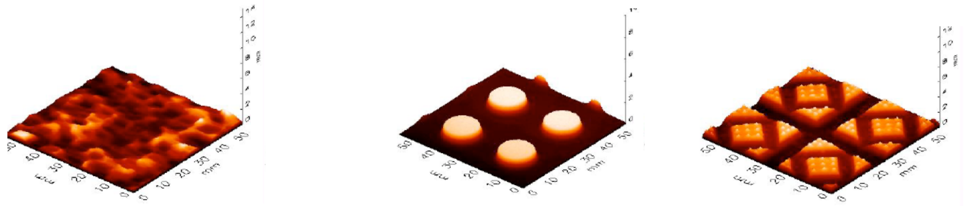
The results, which (like the references in literature) can be biased due to sample preparation as well as tile production differences[10,11,20], were shown to have a maximum deviation of 5% (micro rough tiles) up to 10% (profiled tiles) using the same tile, different tiles from one batch and by comparable measurement techniques with the same settings, available within the consortium.

2. In most referenced literature the use of a basic Gaussian phase correction filter to generate the profile is mentioned.



Group 1 Smooth surface with values of:
Pk = 2.34 µm
Pp = 38.73 µm

Group 2 Non-profiled, gritty surface with values of:
Pk = 58.37 µm
Pp = 258.26 µm



Group 3 Structured surface with values of:
Pk = 396 µm
Pp = 563 µm

Group 3 Profiled surface with values of:
Pk = 368 µm
Pp = 983 µm

Group 3 Profiled surface with asperities with values of:
Pk = 923µm
Pp = 1183 µm

Figure 3. Examples of the range of tile surfaces tested.

For the actual correlation analysis a number of in total 18 tiles (specified beforehand as "low", "medium" and "high slip resistant", with tile surfaces differing from smooth to profiled (figure 3)) were tested, as well as additional 22 re-sampled tiles, the latter using only selected slip resistance test methods.

Based upon the possibilities of the optical topography measurement both the roughness data parameters (table 1) and the corresponding unfiltered primary data parameters, measured on representative areas on each tile were each correlated with the common slip resistance measurements (as far as the profile permitted a valid measurement):

- the Ramp test acc. to DIN 51130 (oil, shoe) and DIN 51097 (water, detergent, barefoot)
- the Pendulum according to BS 7976 (4S and TRRL sliders, wet and dry)
- the Tortus test according to BCRA (with leather and rubber, wet and dry)
- the biomechanical friction tester according to adapted EN 13287 (different shoes, glycerol and water with detergent, with specific settings (normal force 400 N, horizontal sliding velocity 0,3 m/s, forward heel slip at angled contact (7°).

As a basis for the correlation analysis the coefficient of determination R^2 value, as derived from each graphical correlation between surface parameter and specific slip measurement, was used. This value specifies the variation in the dependent variable (slip resistance value) that is predictable from the variation of the independent predictor variable (surface parameter), and indicates the validity and sensitivity of the correlation. These values have been classified according to "significant" (higher 0,79), "Moderate" (0,55 – 0,79) and "No correlation" (below 0,1).

After a first grouping of the tiles in "micro-rough" (10 tiles) and "profiled" (8 tiles), the first correlation scoring with each slip measurement method was assessed. After this first step the grouping of the tiles was investigated by evaluating the changes in the correlations when re-grouping tiles with a gritty profile, below being structured or even profiled, to find the limit surface transition setting for the micro rough to the structured and profiled range surfaces. This re-grouping (with use of re-sampled tiles) was used to check grouping consistency. Based upon this iterative evaluation general surface characteristics for grouping of tiles and the classification of the tiles "safe when contaminated with water" (based upon correlations with the Ramp test according to DIN 51079, Pendulum wet, Tortus wet and the water-based biomechanical tests) were established. The same was done for "safe when contaminated with other liquids contaminants with a viscosity higher than water, such as oil and grease" based upon correlations with the Ramp test according to DIN 51130 and the glycerol-based biomechanical tests.

4. RESULTS AND DISCUSSION

As a discussion of the individual correlations would exceed the framework of this paper, the main conclusions are presented here. The research was not used to asses the validity of the slip measurement methods, but differences in the slip measurement variability for the different surface groups bias the established correlations.

It was established that the primary parameters (as expected) indeed show a better correlation with slip resistance than the calculated roughness parameters. Especially the primary parameters Pk (core roughness from the material portion curve[15], Figure 4) and the Pp value (maximum height of the profile above the mean line of the profile[16], Figure 5) show consistent correlations ranging from "moderate" to even "significant", which seems comprehensible from their definition, indicating the correlation to friction under load conditions (Pk) and grip (Pp).

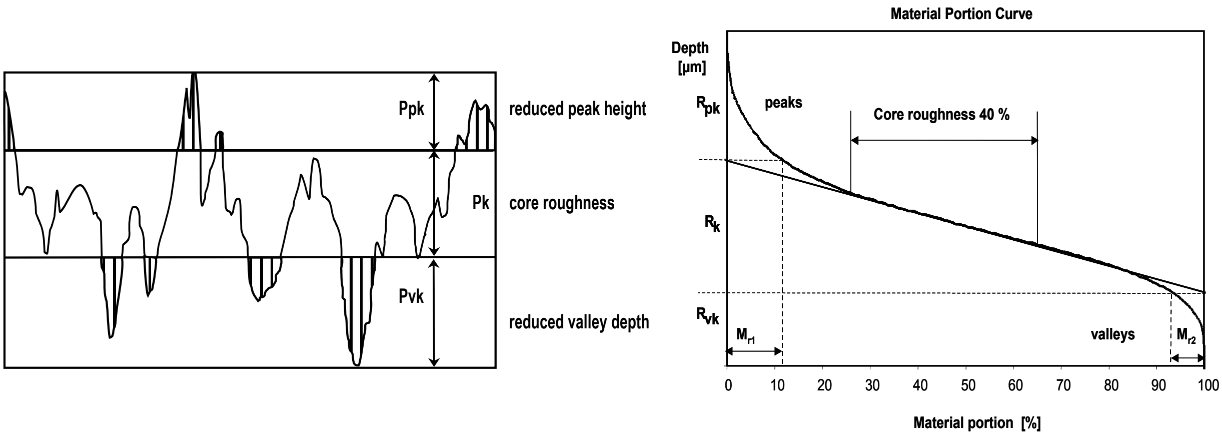


Figure 4. Core roughness depth of the roughness core profile of the load-bearing area of the surface, calculated from the material ratio curve (EN ISO 13565-2) from the cut off points of the line of best fit, which shows the lowest gradient over 40% of the material portion, on the Y-axis at materials portion = 0 % and 100%.

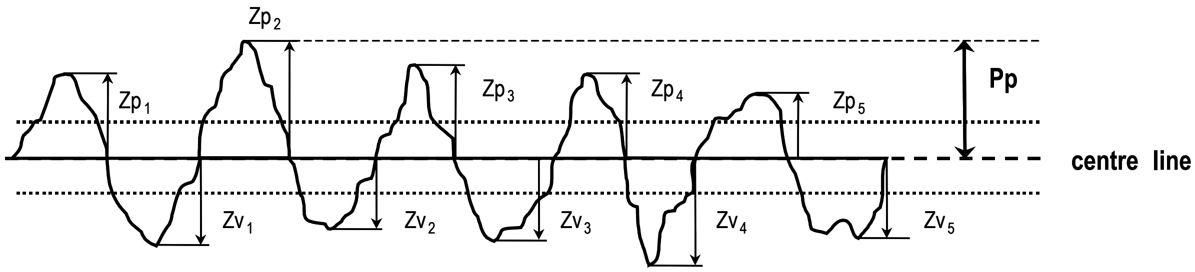


Figure 5. Maximum height of the profile above the mean line within the sampling length (EN ISO 4287).

These parameters were tested to provide the means to specify a relevant grouping of surfaces (see figure 3):

- Group 1. Smooth surfaces with Pk< 50 µm. Pedestrian surfaces within this group tend to be slippery when contaminated. For these surfaces no relevant general correlation with the different measurement methods can be defined, especially with oil contamination, as other parameters than surface topography are significant, leading to large differences in different slip test methods. This applies to most polished tiles.
- Group 2. Non-profiled, essentially even surfaces with gritty touch with 50 µm < Pk < 100 µm and 90 µm < Pp < 200 µm. These are tiles which can be descried as “micro rough”.
- Group 3. Profiled, textured or structured surfaces with Pk > 100 µm and Pp > 200 µm. This range includes higher roughness as well as profiled surfaces. For this range additional surface parameters can be applied to investigate slip resistance functionally, including geometric aspects and shape factors for different components of the surface texture. In the project, segmentation techniques have been developed to separately address these aspects.

The relevance of the grouping is illustrated in figure 6: different surface groups show different correlations with slip resistance. This implies that comparative studies, as used for classification purposes, overlapping the total range of surfaces, cannot always find a general correlation.

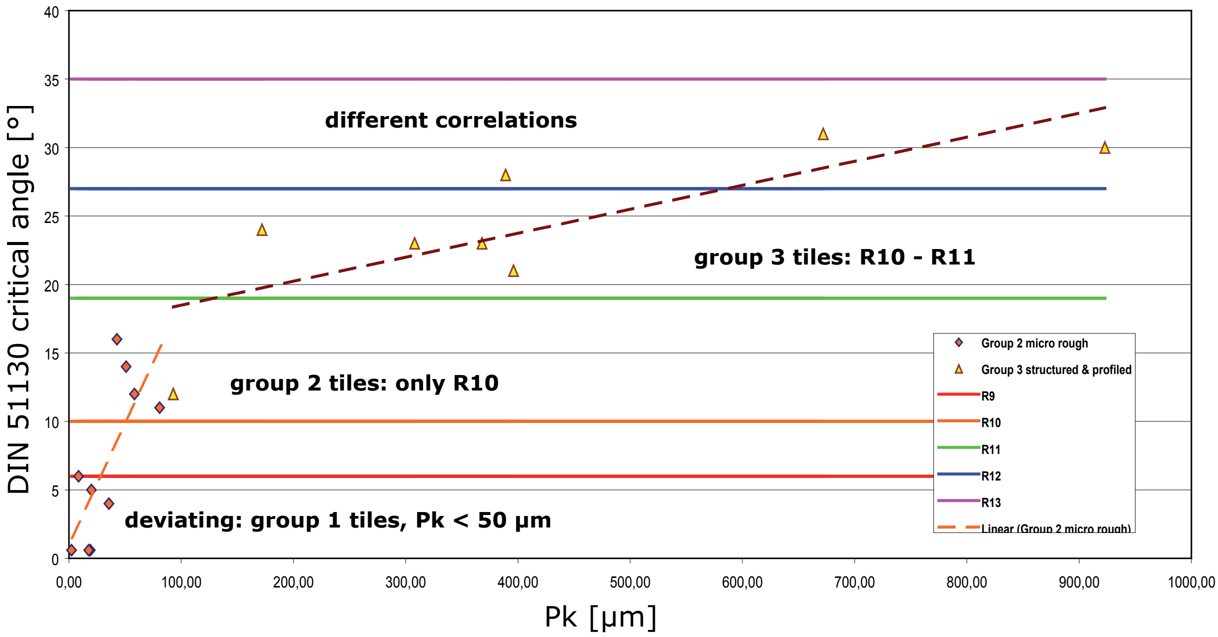


Figure 6. Correlation of Pk with slip resistance according to DIN 51130.

The relevance of these parameters is confirmed by using these parameters to predict slip resistance as defined by the different methods. A reliability of the prediction of up to 90% is reached, which has lead to de development of surface based design rules for the participating SMEs to develop slip resistant surfaces. These settings will be available in the future.

5. THE PUBLICLY AVAILABLE SPECIFICATION - SLIPSTD PAS DOCUMENT

It is acknowledged that the results of this preliminary study require suitable validation. The SlipSTD consortium believes that the results are an important starting point to achieve a harmonized characterisation method for measuring the slip resistance of floor coverings based on surface characterisation, possibly eliminating the need for multiple slip resistance tests.

Based on research carried out, the PAS Document, which will be available through the industrial organisations involved in the project, categorizes hard floor coverings into three classes according to the existence and implementation of a restorative cleaning and control measures to reduce the risk of slip accidents, for which specific recommendations are formulated [24]:

- **Class 1:** Hard floor coverings for internal pedestrian areas that are foreseeably clean and dry and are routinely maintained as such. In this case no surface requirements, due to the low probability of slipping, should be set.

- **Class 2A:** Hard floor coverings for internal pedestrian areas foreseeably contaminated with water and/or dry contaminants.
- **Class 2B:** Hard floor coverings for internal pedestrian areas foreseeably contaminated with other liquid contaminants with viscosity higher than water, such as oil and grease.

The three classes help to identify the available controls, including the choice of appropriate floor coverings, specified using the developed surface characterisation and surface requirements to reduce the slip risk (table 2). Dry and clean floor coverings of any group present low slip potential. Due to cleanability and possible impact on slip resistance by retaining contamination it is not advisable to use floor coverings with Group 2 and Group 3 surfaces in foreseeably dry and clean areas. Accordingly, only the surface of floor coverings in foreseeably contaminated areas (Classes 2A and 2B) surface requirements, ex-factory and post installation, are specified in table 3.

	Surface groups		
	Group 1	**Group 2**	**Group 3**
Class 1	No requirements	No requirements / not advisable	No requirements / not advisable
Class 2A	Not applicable	P_k> 50 µm and P_p> 90 µm	P_k> 100 µm y P_p> 200 µm
Class 2B	Not applicable	Not applicable	P_k> 150 µm and P_p> 300 µm

Table 3. Proposal for surface characteristics for hard floor coverings for internal pedestrian areas, ex-factory and post installation.

In addition to the proposed characteristics shown in table 3, hard floor coverings used in areas likely to be contaminated are also expected to meet the national slip resistance values and existing regulations and directives for foreseeably contaminated applications, some of which are referred to in the PAS document.

6. CONCLUSIÓN

The SlipSTD project proposes to use a different approach to assessment of the slip potential of hard floor coverings, by measuring surface properties and establishing those surface features that best correlate with slip resistance, as determined by the established test methods. Although the SlipSTD consortium recognises that the results of this preliminary study require suitable validation, the SlipSTD consortium believes that the results are an important starting point to achieve an ultimate objective of establishing a harmonized characterisation method for measuring the slip resistance of floor coverings based on surface characterisation.

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