NEW PRACTICE-ORIENTED TESTING POSSIBILITIES REGARDING THE DURABILITY OF SLIP RESISTANCE AND CLEANABILITY

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1. ABSTRACT

Like required by U.S. Building codes and the Americans with Disabilities Act (ADA), the replacement of the European Construction Products Directive by the European Building Products Regulation in 2013 [1] has put more pressure on the manufacturers and users of flooring materials to concern themselves with the aspects of durability of such characteristics like slip resistance and cleaning. Experts as well as testing institutes are increasingly commissioned to evaluate the durability of slip resistance and cleaning behaviour as well as the susceptibility to soiling of tile surfaces in private and occupational areas during use. In Australia standardized test like the Sustainable Slip Resistance test (SSR) are in use [2], based upon pendulum testing validation, but lack an objective, topography based evaluation of actual wear independent of the slip measurement method, which would facilitate the interpretation of the slip risk as proposed in the Slip STD Public Available Specification [3], providing a surface based slip risk classification, taking into regard the expected contamination and the cleaning and control measures on site. This paper addresses the background, the current status as well as the potential of new practice-based measurement and evaluation methods for slip resistance as well as the cleaning behaviour of tile surfaces and their durability based upon surface topography measurements.

2. INTRODUCTION

The sustainability of functional properties of ceramic surfaces is an increasingly important issue. The European Construction Products Regulation implemented in 2013 requires proof of the durability of essential product properties and the compilation of a performance declaration for CE-marked products (replacing the conformity declaration) for their economic life cycle [1]. The durability has to be declared or proven by a corresponding method, if available. Based upon the growing awareness of the need for specification of long-term performance in the market, FGK has focussed on the investigation of practice-relevant wear simulation method, aided by an objective characterization possibility to simultaneously analyse the changes in slip resistance and cleaning behaviour as a function of the actual wear on site.

3. SLIP RESISTANCE – A SLIPPERY SUBJECT

In Germany alone, there are more than 1000 slipping workplace accidents each year, including some fatalities, where the financial cost of rehabilitation and compensation exceeds 330 million Euro annually. Numerous renowned institutes therefore concern themselves with measurement and evaluation of slip risks in laboratory and on site, with a large variety of slip measurement methods. Due to non-matching reference or calibration materials and different slip mechanisms these however, depending on the type of surface, do not always offer a comparable estimation of the slip risk. Although slip resistance has been specified as essential characteristic for the CE marking of floor tiles, no corresponding harmonized single test could yet be defined. In 2011 the European standardization committee CEN/TC 339 (on measurement of slip resistance in pedestrian areas) decided to put forward a technical specification, including three different, but in different member states accepted testing methods: the inclining ramp walking methods, the pendulum test method and the GMG 200 method for the measurement of the dynamic coefficient of friction (DCOF) (CEN/TS 16165 [4]).

The ramp method is based on the determination of a critical inclination angle at which a person slips on a sample, covered with oil using reference shoes for occupational areas or flooded with water with a surfactant for barefoot applications. This angle classifies the tested surfaces in R-classes, ranging from R9 up to R13, referring to applications with different expected amounts of slippery media (water, oil or grease) for the occupational and public area, for higher requirements combined with additional measurement of the displacement volume. For the barefoot areas, as in swimming pools, shower areas and in spa environments, the surface is classified as A, B or C-class, depending on the amount of expected water on the surface. This method is generally used in Germany. The pendulum test is based upon the deceleration of a rubber slider, mounted on a spring-loaded slider unit on a pendulum arm, which swings over a surface with a defined contact path. The values are obtained measuring the overswing of the pendulum arm after contact, starting from a horizontal position. These values are compared to specified thresholds, each indicating a different expected slip risk. The pendulum test for tiles has been well established in the UK as well as in Spain. The dynamic coefficient of friction depends on the resistance to move of a slider when pulled over the surface in dry or wet (with water or water with a surfactant) conditions. The slider material generally is rubber or leather (for dry applications). In Germany, safety threshold values have been established as a method to evaluate and control slip resistance on site under occupational conditions.

These methods can differ strongly dependent on the surface tested: The ramp approach incorporates static as well as dynamic friction during human walking. Test persons have to qualify themselves using reference slabs. The operator-based measurement has a high uncertainty at lower angles, but provides the only possibility to measure highly profiled surfaces. Other drawbacks are that, besides the problem of availability and consistency of footwear, slip media and calibration boards, it only can be used in the laboratory. As the pendulum was originally developed to simulate the braking effects of car tires on roads, it is portable, but puts high demands to the experience and training of the operator. Smooth surfaces can be easily overestimated due to sticking effects, whereas highly profiled surfaces are difficult to measure due to the influence of the profile on the point of impact. The measurement of the dynamic coefficient of friction can also be performed on site using self-propelling devices. It is less dependent on human influences, but also leads to an over-estimation in on smooth surfaces due to sticking, as well as an underestimation at a certain profile depth due to the loss of contact area among other limitations. So results have to be treated with caution.

These differences underline the need for a separate objective evaluation of slip resistance over the range of available surfaces, and especially for changing slip resistance due to wear of the surface.

4. CLEANING BEHAVIOUR AND SUSCEPTIBILITY TO SOILING

Another aspect always incorporated in the discussion regarding increased slip resistance is the cleaning behaviour of the surface. The general rule "the higher the slip resistance, the more cleaning effort is needed" puts extra pressure on meeting performance requirements. Staining characteristics are measured according to the standard (EN ISO 10545-14), however with staining agents, not relevant in most problematic applications, especially for areas with frequent pedestrian traffic, and providing no differentiation of actual differences in soiling and cleaning behaviour. Practical experience shows that in many cases no correlation of this test method to actual cleaning problems can be established. Therefore manufacturers are already applying own indicative manual tests with reference dirt, whose results are not accessible to the customers. FGK was commissioned by a large internationally operating discounter to initiate a new approach to this problem. The action was initiated by large scale grey shading and locally visible mosaic effects in the tile surface in the stores, although all tiles had passed the highest staining class (Fig. 1).

Figure 1. *Heavy shading of the surface, leading to strong colour-transitions on the floor (left) and locally highly visible mosaic effects (right)*

A relevant test had to be developed, addressing two aspects of the problem: besides the cleaning effort also the soiling behaviour had to be investigated: cleaning with relative low effort, but necessary on a frequent basis is a complaint often formulated in assessments of unsatisfactory performance of floorings. To address this, a reference test, based upon recommendations of the German Industrial Association for Personal Hygiene and Detergents for testing the quality of all-purpose cleaning agents [5] was adapted for the ceramic surface [6]. It is based upon the development of a mixture of peanut oil, kaolin and soot, intended to simulate adhesive greasy soil with dirt particles as trodden in from the street, wear residues from shoe soles and shopping trolleys and contamination from groceries and spills. This mixture has to be aged for one month at room temperature to form a soiling agent with the required dispersion and adhesion properties. Prior to use it is thinned and mixed with isopropanol to a spray solution, which then is applied to the test specimens using a template (Fig. 2a). The samples are then stored for three days at room temperature, allowing the dirt to adhere to the surface before testing.

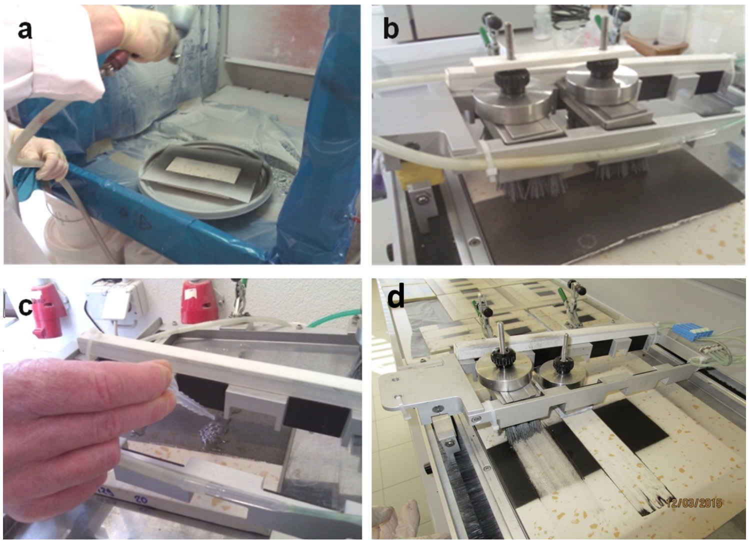


Figure 2. *Application of the dirt to the tile (a) and testing with brushes mounted in the multi-track scrubber (b). In (c) the application of the cleaner onto the test track is shown. The result of the test can be seen in (d)*

The assessment of the cleanability is performed in an automatic multi-track scrub tester by wiping with prepared brushes, sponges or cloths. Fig. 2b shows the use of brushes, as typically used for the large-area maintenance cleaning of hard floor coverings. To ensure corresponding area pressure, testing is performed with an additional weight applied to the brush. After mounting of the brushes, 2.5 ml of a common maintenance cleaning agent (in most cases the actual cleaning agent as applied in the corresponding application area) in its regular dilution is distributed onto the soiled tile surface by means of a pipette in the track of the brush (Fig. 2c). In a multi-track scrubber, parallel tests can be performed. Before being used for the first time, new brushes must be run in on a clean tile with about 100 strokes prior to testing, as the cutting edges of the brush ends would distort the measurement. The brush speed is set at 20 strokes/min (1 stroke = forwards and backwards movement).

A large number of preliminary tests have been conducted to determine the number of cleaning strokes needed to obtain a clear differentiation of the surface functionality that can be correlated with practice. Besides the number of the strokes needed to clean the surface (if possible), the sharpness of the transition of the cleaned/clean area is taken into consideration. The latter is a measure for the tendency of dirt penetration into the surface, leading to a grey discoloration, often observed in practice. This opens the possibility to visually evaluate the removal of coarse dirt as well as to perform an assessment of how surface will react to soiling on a long term. It is important to notice that these results can be very different if the cleaning system is adjusted: using other brushes or pads for specific surfaces leads to better results, indicating how the regular cleaning and maintenance of the floor can be optimized. For the necessary validation of the method remaining uninstalled tiles as well as installed tiles from the discounter stores were sampled from different locations with clearly different soiling behaviour. In the laboratory these tiles were mechanically and chemically cleaned by means of ultrasound and alternate alkaline/acidic cleaning and then tested. The results after the 6^{th} and 15th stroke as well as after 15 additional strokes (after brush cleaning and renewed application of cleaning agent) were found to be suitable for a relevant classification of the cleaning and soiling behaviour of the surface in regard to the actual behaviour of the tile surfaces on site (Table 1).

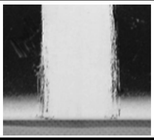
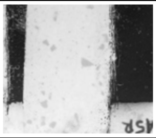
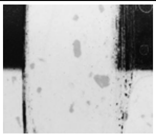
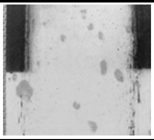
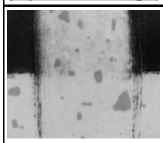
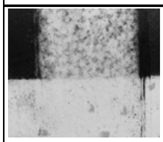
reference	assessment rating	residual dirt			transition cleaned - clean	expected cleaning requirement and dirt susceptibility
		after 6 strokes	after 15 strokes	after 15 + 15 strokes		
	5 very good	not visible				easy to clean, not susceptible to dirt
	4 good		not visible			easy to clean, not susceptible to dirt
	3 sufficient		slightly visible	not or hardly visible	not visible	standard cleaning requirement, not susceptible to dirt
	2 insufficient		slightly visible	local residues, slightly grey in places or over the entire surface	slightly visible	higher cleaning requirement, susceptible to dirt
	1 deficient		clearly visible	clearly visible	clearly visible	higher cleaning requirement, very susceptible to dirt
	0 poor		pronounced	pronounced	pronounced transition	cleaning hardly possible, very susceptible to dirt

***Table 1.** Assessment rating of the cleaning test results correlated to the expected cleaning requirements and susceptibility to soiling.*

The soiling pattern on site was classified according to the described rating for the laboratory specimens regarding the severity of the existing dirt pattern. A significant agreement of the results of the laboratory tests with the assessments on site could be established. Differences in the results could be explained by scaling effects due to high water hardness, which could be detected as carbonate traces by acid treatment. Fig. 3 shows the replication of the soiling patterns on laboratory scale related to the actual situation on site. In the cases that deviated significantly from this correlation, non-optimal cleaning on site (dosing of the cleaning agent, speed of cleaning) could be determined as the cause for the differences in the assessment.

Based on the defined potential of the test, a qualitative and quantitative statistical analysis of the factors influencing the visual assessment on laboratory scale was conducted. The influence of the amount of cleaning agent, condition of the brushes, application of the dirt, drying time and the visual interpretation of different test samples by different operators were tested, based on a design of experiments concept. The condition of the brushes was established as the most important influence on the assessment, which eventually can lead to a deviation in the rating. Based on these results the actual optimized test procedure was transferred into a working description, available for customers, institutes and development departments in the tile sector.

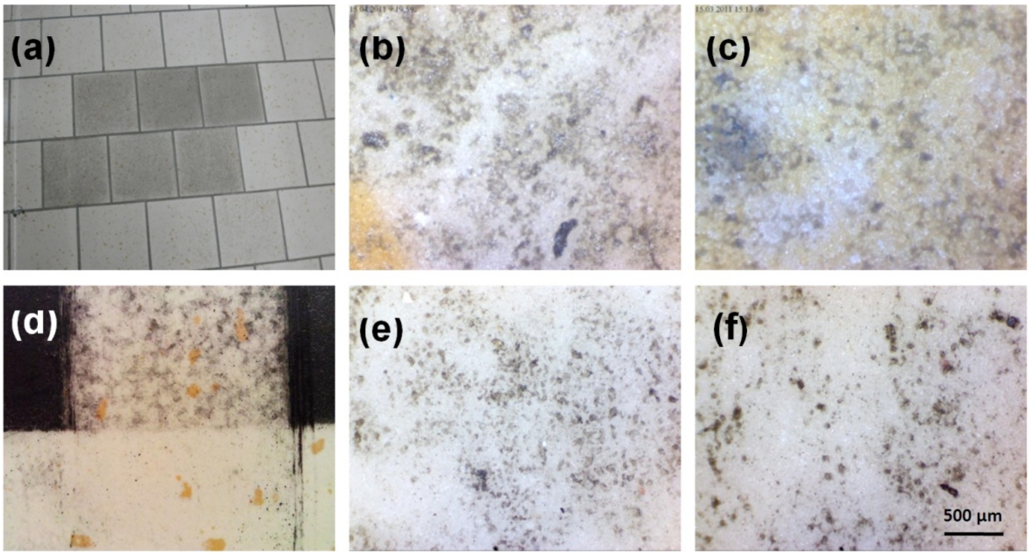


Figure 3. *Comparison of the assessment on site with the cleaning tests: (a) photograph of soiled tiles on site, (d) photograph of the reproduced soiling pattern in the laboratory, (b) microscope image of the surface of soiled tile taken from (a), (e) microscope image of the surface of the tested surface from (d), (c) microscope image of another tile with less soiling, (f) microscope image of the tested surface from (c)*

5. TOPOGRAPHY AS AN OBJECTIVE VALIDATION TOOL

To assess the effects of slip resistance in combination with the cleaning and the soiling behaviour, especially when these effects have to be regarded over the period of use, another objective parameter is necessary, which can describe the nature and the changes of the actual surface, independent of its functional behaviour. In the scope of the European Collective Research Project "SlipSTD – Development of Slip-Resistant Standard Surfaces", as part of an international consortium of leading institutes in the field of ceramics, tribology, work safety and statutory accident insurance as well as architect organizations and tile manufacturers [7], FGK developed a method for the characterization of ceramic surfaces by means of optical profilometry based upon the international Geometrical Product Specifications (GPS) - Surface texture Standards ISO 4287 and EN ISO 4288 [8, 9].

A clear correlation of the surface topography with the slip risk to be expected for different surface types could be established. This interpretation made it possible to generate an interpretation and classification of the surface, independent of the different interpretations of slip resistance as a result of using different test methods. This classification includes assessment of type and amount of contamination expected combined with conditions to be met regarding control measures and cleaning procedures implemented for the specific application in a holistic approach [3, 7]. The method is based on the determination of topographic data, based on unfiltered roughness values, which can deliver a useful description of the actual profile. It has to be noted that the well-known Ra and Rz values represent filtered parameters which can hide actual relevant differences in surface profiles. Especially for relatively rough-surface tiles, contact measurements are pushed to their limits and can no longer be used to image the characteristic height of tile profiles. Optical measurement with chromatic aberration, the spectral shift of backscattering spectrum of focussed white light, enables the handling of a necessary larger measurement area (up to 56 mm x 56 mm) with an adjustable height range (up to 1 cm) specifically defined to characterize tile surfaces with acceptable effort [3].

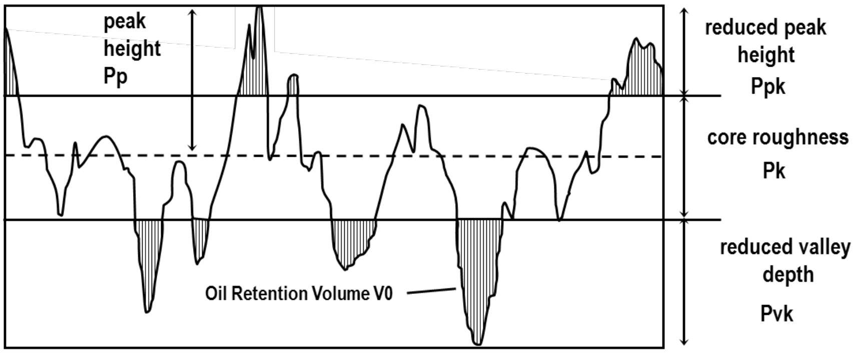


Figure 4. *Relevant topography parameters defining the slip resistance and cleaning and soiling behaviour*

To interpret the surface amplitude parameters, shape factors as well as parameters, specifying the material ratio curve in the depth of the profile were incorporated (Figure 4). After an extensive statistical correlation analysis the core roughness Pk, defining the main load carrying part of the profile as well as the parameter Pp, the height of the profile above the mean line, representative for protruding peaks in the profile, were established as significant parameters defining the "grip" of the surface. The reduced valley depth below the core roughness and the calculated "oil retention volume" in this depth range were found to define the actual cleaning and soiling behaviour.

A significant result of the project was the specification and verification of the suitability of the different slip test methods on different surface types, which now can be differentiated quantitatively, using the mentioned surface parameters as shown in fig. 5.

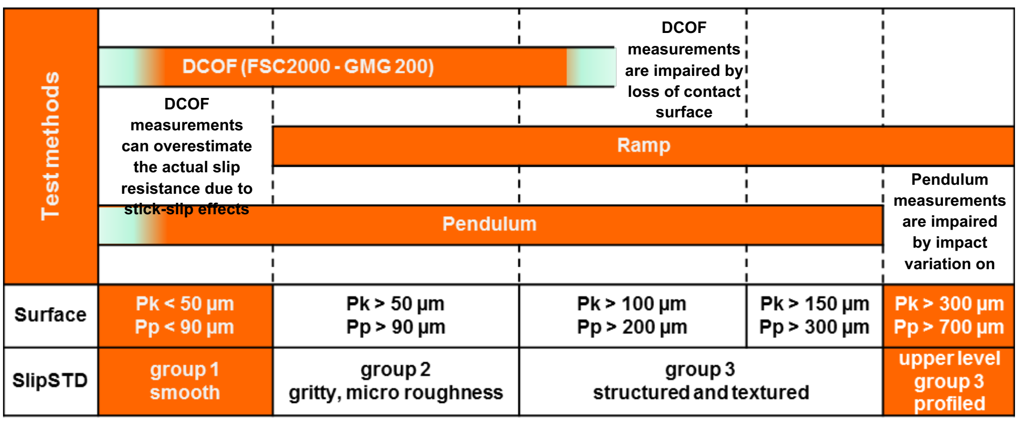


Figure 5. *Suitability of different slip test methods dependent on the surface characteristics*

This result confirmed the aforementioned differences between the methods in specific surface ranges and explains why it is not possible to establish correlations between these methods over the complete span of the available surface topography. It confirms that on smooth surfaces other parameters like slipping medium, measurement speed and slider type are more significant than the actual topography and that, as roughness increases in significance, correlations between the methods can be established. At higher roughness rates this correlation is lost again due to the loss of contact surface, depending on the material and geometry of the slider/footwear material and the more important role of profile shape parameters. This has an important effect on the assessment of durability of slip resistance.

6. DURABILITY OF SLIP RESISTANCE AND CLEANING BEHAVIOUR

The implementation of the surface topography characterization creates a basis to objectively asses and evaluate the actual changes of slip resistance as well as cleaning behaviour in time. To be able to use this method on installed tiles, a duplication technique was used, accurate enough to establish relevant changes in surface topography, without the need for extraction of tiles from the actual floor. A silicone duplication material, able to duplicate with an accuracy of 2 µm by pouring a two component mixture on the surface is used, ready to be extracted after ca. 20 minutes.

Figure 6. *Duplication technique used (left) and visualization of the duplicate of the surface (right, inverted).*

To simulate the so specified actual changes due to use and abrasion of the surface on site a suitable abrasion method had to be developed. As the abrasion according to the EN ISO 10545-7 test method (PEI) was proven to generate a non-uniform abrasive pattern (with a stronger abrasive effect at the rim of the tested surface, leading to an exaggerated interpretation of actual abrasion for dark coloured surfaces) another approach had to be taken.

As the mentioned international approaches are based upon linear abrasion and small treated surfaces, radial abrasion for larger samples had to be considered, as in Germany the ramp method, requiring sample sizes of 50 cm x 100 cm is established as reference method. This sample size provides a surface which can also be measured by the other methods as incorporated in the European Technical Specification [4].

The use of abrasive pads in a single-pad cleaning device was optimized and validated using topography measurements to compare the laboratory results with identical surfaces in use on site. It could be established that specified abrasion patterns (indicated as cycles) over the surface can be correlated to actual wear effects: 20 abrasive cycles in laboratory correspond to the effects of wear after 1.5 years in a highly trafficked area with abrasive dirt (discount store, mall, train station hall). Here similar changes of the profile core roughness and the reduced peak heights, so smoothing the surface, could be detected in the same magnitude as found in the surface on site, as shown in figure 7.

In an extensive study of different floor surface types the method showed that most surfaces, designed for slip resistance requirements show a significant decrease in the slip resistance in their first 1.5 year of use: reductions of 30 up to 70% for the results of the ramp method as well as of coefficient of friction measurements are no exception (Fig. 8). Even for highly profiled tile surfaces small changes in the sharpness of the protruding parts have a significant influence on the slip resistance and can lead to a significant decrease. In some cases this leads to the transition of slip thresholds, implying a different slip class of the actual surface as upon installation. This indicates the critical character of this effect in regard to the required long term performance as incorporated in the CE Marking requirements und emphasizes the need for the further development this method in regard to the European building products regulation. This approach has been systematically implemented to support the design and development of durable slip resistant surfaces.

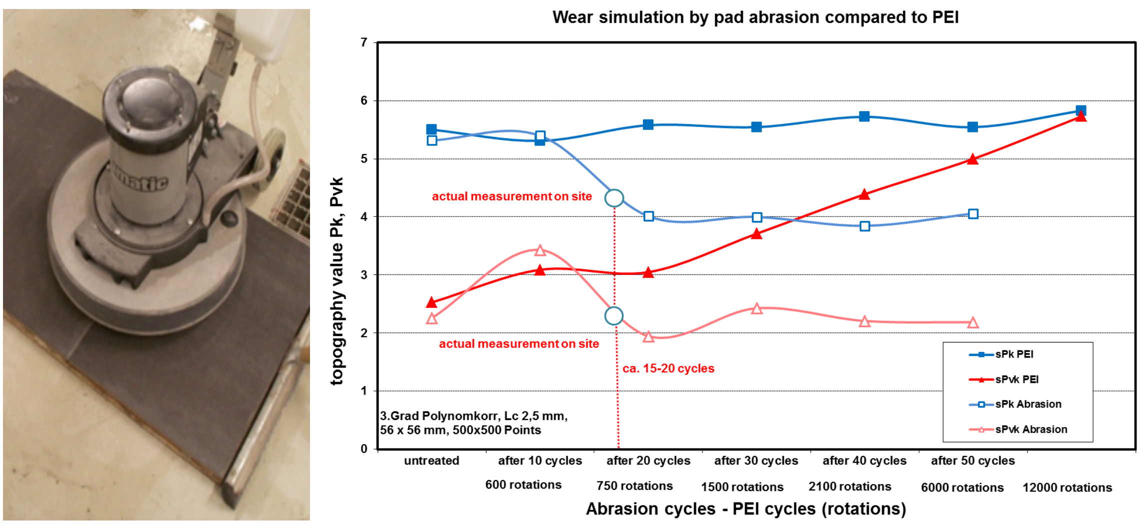


Figure 7. *The validation of the abrasion simulation method by topographical comparison with PEI results and an actual surface on site, here demonstrated by the Pk and Pvk values (surface group 1 tile, see also fig. 8)*

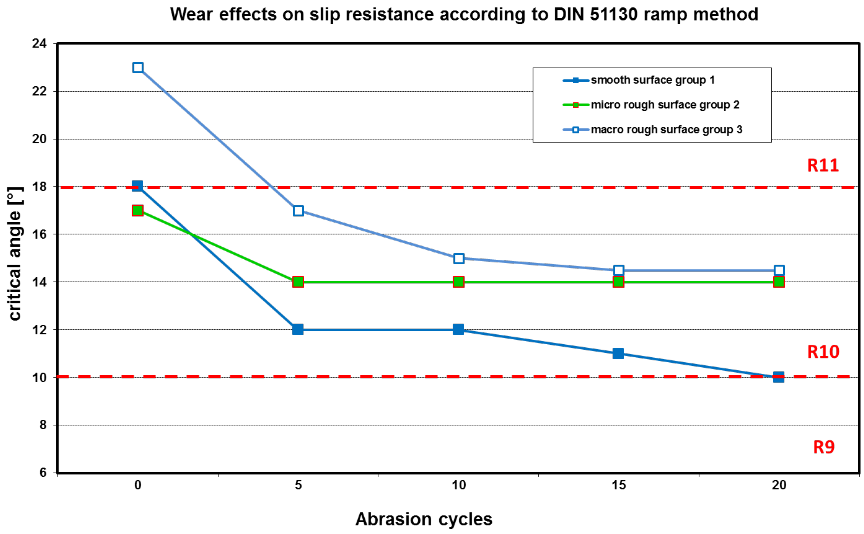


Figure 8. *The decrease in slip resistance due to abrasion as measured with the ramp method according to DIN 51130*

The measurement of slip resistance durability can now simultaneously be assessed with the durability of cleaning effects. The abraded samples were tested and rated using the aforementioned method (table 1) and investigated with the help of microscopy and the topographic characterization method. So non-obvious effects can be explained:

It could be established, that increased dirt susceptibility was not only depending on the roughness as such, but also, if not prominently, on the percentage and the depth of the pores and depressions in the surface, not relevant for slip resistant. While the slip resistance tends to decrease, cleaning behaviour of the surface can also show a negative development in the first abrasion stages, by removal of the top layer of the surface (e.g. for a surface group 2 tile with a factory seal application): pores und inclusions are uncovered, leading to a deterioration of cleaning behaviour. Later on these pores, depressions and holes can be smoothened out again, in which case the cleaning is improved and the soiling is reduced (Fig. 9), while the slip resistance stays low. This change can be quantified by the change of the reduced valley depth Pvk, which initially increases, and then is reduced, indication the decreasing depth of pores and holes (see also fig. 7).

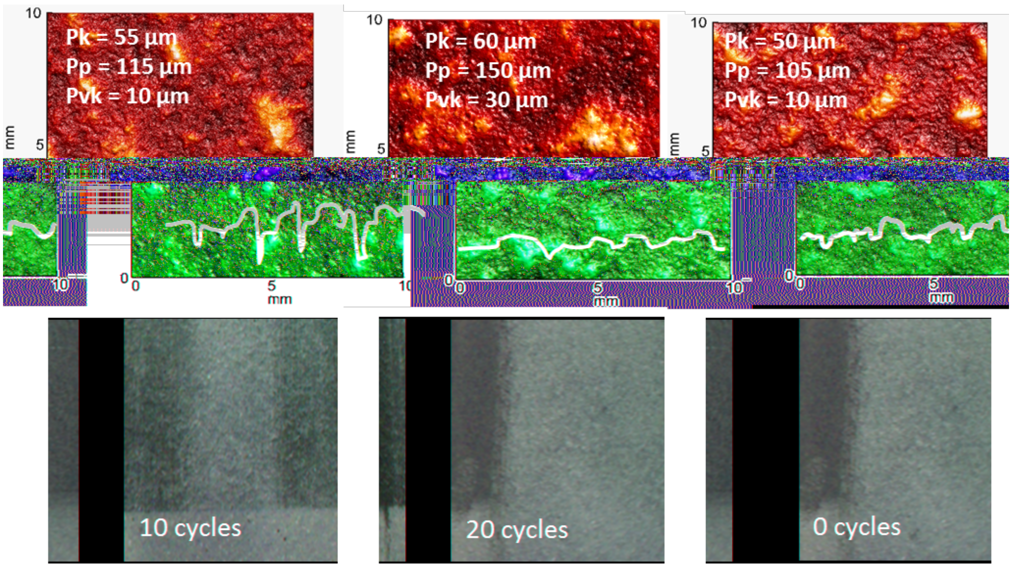
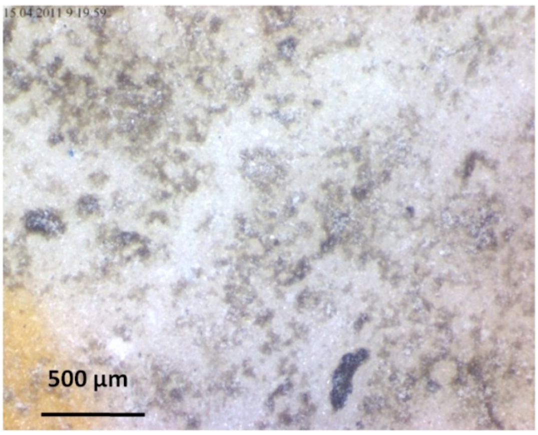


Figure 9. *Topographical presentation of the effects of wear on a micro rough surface (group 2) (2D representation, profile and characteristic values, above) and the actual cleaning behaviour as measured in the laboratory (cleaned surface, below)*

These phenomena have shown to play a major part in cleaning problems even in the case of polished surfaces. Non-homogeneous factory- applied finishes for unglazed tiles, meant to improve the stain resistance, could be detected as the possible cause for the dirt susceptibility (Fig. 10). These effects can now be analysed quantitatively, enabling the development of design and production criteria to obtain easy to- clean surfaces. For example, for micro rough tiles, a reduced value depth, with a maximum of 6 µm or an oil retention volume sV0, the displacement area in this depth range of maximal 0.3 $\mu m^3/\mu m^2$ could be measured as critical values. Exceeding this value leads to a strong increase in dirt susceptibility. Here mechanical cleaning is ineffective, it requires considerable cleaning effort with the use of deep action cleaning agents containing surfactants.



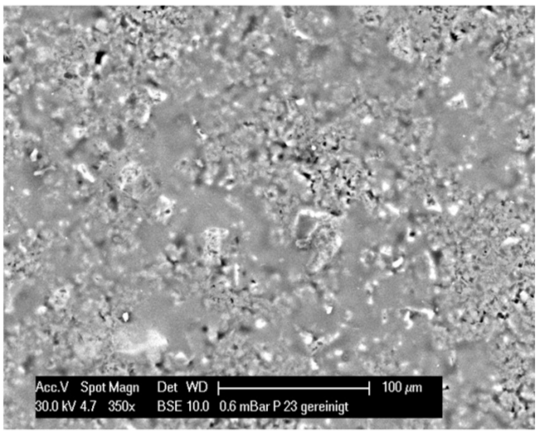


Figure 10. *Microscope image of the soiled surface of micro-rough tile (left) and the scanning electron microscope image of the surface after cleaning (right). The inhomogeneity of the surface coating can be clearly seen on the right.*

7. DISCUSSION

To summarize it can be said that the abrasion method described is proven to simulate wear effects which can be correlated to the wear on site by topography measurements. The method furthermore offers the possibility to correlate different slip durability measurement methods on the same surfaces, as well as to simultaneously evaluate the cleaning properties, using the newly developed test for the cleaning and soling behaviour. So the basis is created for development of durable slip resistant and easy to clean surfaces with low dirt susceptibility. Transfer of the abrasion method into a laboratory set-up, further reducing the manual impact by automated abrasion cycles will help to improve reproducibility and repeatability of the method. Further studies on the wear effects in different application areas can lead to a better understanding of the wear effects in different practice situations. It offers an optimal basis to address the requirements as put forward by the European Building Products Regulation. At present the process is already used by tile manufacturers working in collaboration with the FGK as a practice-relevant development aid and support of production control, where the standard test for staining resistance testing is failing to address actual cleaning problems.

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