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# Measurement and evaluation of skid resistance of concrete floors

## *Pomiary i ocena odporności na poślizg posadzek betonowych*

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**Abstract.** The assessment of slipperiness of industrial or domestic floors is a difficult task. The subjective feeling or experience of slipperiness by the pedestrian should match with objective measurements. This paper deals with the experimental methods applied today to measure skid resistance of floors. In a case study a comparison is made between several experimental and material investigation techniques on the surface texture and composition of a concrete industrial floor, and the experience of pedestrian users of the same floor. The match of both reveals to be rather limited.

**Keywords:** industrial floors, skid resistance, SRT – pendulum test, ramp test, coefficient of friction, micro-roughness.

**Streszczenie.** Ocena śliskości posadzek przemysłowych jest trudnym zadaniem. Subiektywne odczucie lub doświadczenia pieszych przy ocenie śliskości powinny być brane pod uwagę podczas badań. W artykule omówiono doświadczalne metody stosowane obecnie do pomiaru odporności na poślizg. W studium przypadku przeprowadzono analizę porównawczą między kilkoma eksperymentalnymi i materiałowymi technikami badawczymi, biorąc pod uwagę fakturę i skład betonowej posadzki przemysłowej oraz doświadczenia pieszych użytkowników. Zależność ocen jest raczej ograniczona.

**Słowa kluczowe:** posadzki przemysłowe, odporność na poślizg, SRT – test wahadełka, test rampy, współczynnik tarcia, mikrochropowatość.

The slipperiness of floors is a major problem for the safety and health of users and inhabitants. Falls as a consequence of slips on a slippery floor are not only a prime cause of accidents on the shop floor, but also of domestic accidents. The problem is complex, because multiple factors have an influence [1]: type and texture of the floor, soiling, footwear, the user, the applied cleaning procedure and cleaning products, environmental influences. Moreover, the slipperiness of a floor is not only a function of the initial surface characteristics of the floor material (e.g. roughness), but also a function of the floor material evolution with time (e.g. wear, patina, …).

In wet process environments the correct surface profile is essential to provide a safe and efficient working environment [2]. In wet process areas, floors are often laid to falls to allow water and liquid spillages to flow to the drains. However, free draining floors mostly necessitate the need for steep falls which require an appropriate profile to be safe. Where personnel are required to push bins and racks over a floor with complex falls, the need to prevent the load from rolling downhill can increase the likelihood of strain injuries as well as slips, trips and falls. Generally, flatter floors will be safer [3]. Engineering solutions or a change of working procedures may be required as well as investigating the effect of cleaning and footwear. A compromise between ease of cleaning and slip resistance is required. Smoother floors may require more frequent cleaning, while rougher floors need more aggressive cleaning.

The choice of smooth or textured floors in process areas is not always clear-cut. The two statements ‘There will be occasional spillage in the process area, therefore we need a textured floor to avoid slip incidents”, and ‘There is occasional spillage, therefore we need a smooth floor so that spillage can be cleaned up quickly and easily”, may both be correct. If spillage is too frequent, it may be impractical to clean it up immediately, so a smooth floor would become too slippery. If the spillage is noxious, it may be required that it is removed immediately. Slip hazard will not be an item in that case. Because of the prime importance of safety on the shop floor, performance research has been executed in many countries, leading to a multitude of testing methods and performance and evaluation criteria. The British Health and Safety Executive HSE [1] developed an evaluation methodology based on the use of two instruments: a ‘Pendulum” coefficient of friction (CoF) test measured with the SRT-pendulum (Skid Resistance Tester, Figure 1) and the measurement of the micro roughness of the floor surface with a micro-roughness meter (Figure 2). Besides, a multitude of apparatuses is available for the measurement of the slip risk and the friction coefficient of a floor system. The most important are presented hereafter, with evaluation criteria, if available.

## Skid resistance measuring methods [4]

The SRT-pendulum (Figure 1) although often used in its current form to assess the skid resistance of road materials and pavement surfaces, was originally designed to simulate the action of a slipping foot. The method is based on a swinging, dummy heel (using a standardized rubber soling sample), which sweeps over a set area of flo-

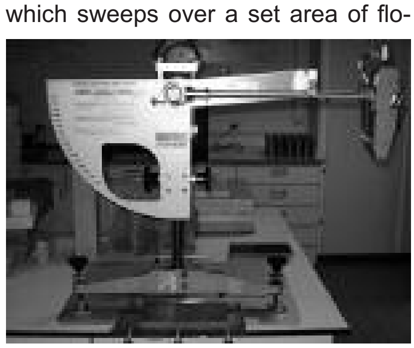

**Fig. 1. SRT-pendulum portable skid resistance tester (BS 7976:2002) [5, 6]**
*Rys. 1. Badanie odporności na poślizg za pomocą przenośnego przyrządu wahadłowego (BS 7976:2002) [5, 6]*

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oring in a controlled manner. For natural stone tiles the test method is described in a harmonized European standard EN 14231:2003, which is based on BS7976:2002 and on the studies of the UK Slip Resistance Group [7]. The test is performed on six specimen, size 150 x 100 mm x thickness, provided with the flooring system to be tested. The instrument consists of a pendulum that freely swings from a predetermined height. The dummy heel slides over the surface of the specimen, reducing the height of the swing movement. The average height difference (SRT-value) for the six specimen is measured on a normalized scale. EN 14231 prescribes the execution of this test on dry as well as on wet surfaces. The advantage of the instrument is the possibility of using it on floors which are already in use, and thus where problems of slipperiness might have been experienced.

The standard NBN EN 14231 limits the application of the instrument to floors with a surface roughness Rz (see further, measured according to NBN EN 13373), lower than 1 mm. It is assumed that a surface roughness higher than 1 mm corresponds to non slippery floor surfaces. For natural stone surfaces the standard NBN EN 1341 indicates that values of SRT higher than 35 can be considered as safe values. The *United Kingdom Slip Resistance Group* [1] recommends classifications presented in Table 1.

**Table 1. Slip risk classification, according to United Kingdom Slip Resistance Group**
*Tabela 1. Klasyfikacja ryzyka poślizgu wg United Kingdom Slip Resistance Group*

| SRT-value (pendulum value) | Slip risk |
|---|---|
| 0 – 24 | high |
| 25 – 35 | moderate |
| 36 – 64 | low |
| 65+ | extremely low |

**Surface micro-roughness.** Figures 2 and 3 show a micro-roughness meter [8], which measures the average surface roughness Rz over a profile of five consecutive measuring lengths of 2,5 mm (5 x 2,5 mm). Rz is the arithmetic mean value of the maximum roughness heights (peak to valley measurements) in five consecutive measuring lengths of 2,5 mm, as shown in Figure 4. A greater value of Rz corresponds to a greater number of extreme

**Fig. 2. Micro-roughness meter**
*Rys. 2. Urządzenie do pomiaru mikrochropowatości*

**Fig. 3. Measuring needle of the micro-roughness meter (accuracy 0.01 micron)**
*Rys. 3. Igła pomiarowa do pomiaru mikrochropowatości z dokładnością 0,01 mikrona*

$$Rz(JIS) = \frac{1}{5}\sum_{i=1}^{5} Ypi + \frac{1}{5}\sum_{i=1}^{5} Yvi$$

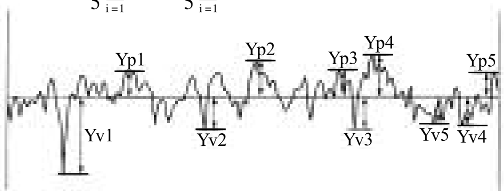


**Fig. 4. Calculation of the Rz-value with 5 maximum peak to valley measurements**
*Rys. 4. Obliczenie wartości wskaźnika Rz na podstawie pięciu największych wartości pików i dolin profilu powierzchni*

peaks and valleys in the profile, which obviously increases the friction or hooking resistance and thus also diminishes the risk of slip. A disadvantage of a higher Rz value might be that dirt on the floor can be more resistant and more difficult to remove. The British Health and Safety Executive proposed an evaluation table for potential slip, based on Rz micro-roughness values, applicable for water-wet, low pedestrian activity areas (Table 2). When other liquids are present as workplace contaminants, the

**Table 2. Potential for slip classification, based on micro-roughness values, for water-wet, low activity pedestrian areas**
*Tabela 2. Klasyfikacja podatności na poślizg na podstawie mikrochropowatości powierzchni mokrej z niewielkim ruchem pieszym*

| Rz surface roughness (micron) | Potential for slip |
|---|---|
| < 10 | high |
| 10 < Rz < 20 | moderate |
| > 20 | low |

required surface roughness will generally depend on the viscosity or thickness of the contaminant (Table 3). Further aspects that have to be considered in evaluating the pedestrian slip potential of a flooring are the cleaning regime (frequency, efficiency), the type of footwear worn in the areas (soling material, tread pattern and condition), environmental and human factors. Supplementary methods have been developed to take into account additional factors besides wetting and contamination. Two of these methods are described hereafter. However, none of these methods obtained general acceptance up to now.

**Table 3. Minimum floor roughness levels required for typical workplace contaminants**
*Tabela 3. Minimalna chropowatość posadzki zależnie od typowych zanieczyszczeń posadzki w miejscu pracy*

| Minimum roughness Rz [micron] | Contaminant |
|---|---|
| 20 | clean water, coffee, soft drinks |
| 45 | soap solution, milk |
| 60 | cooking stock |
| 70 | motor oil, olive oil |
| > 70 | gear oil, margarine |

**Classification according to the Ramp Test (Schiefe Ebene, Ramp Test).** This method involves the use of a test subject who walks forwards and backwards over a contaminated flooring sample. The inclination of the sample is increased gradually until the test subject slips (Figure 5). The average angle of inclinationat which slip occurs can be used to calculate the CoF of the flooring. The test can be made barefootand with soap solution as contaminant (DIN 51097:1992) or with standardized heavily cleated safety boots and motor oil as contaminant (DIN 51130:2004) – Figure 5. The inclination of the ramp can vary between 3° and more than 35°. Five classes are specified, according to the determining inclination angles (Table 4).

In other countries the ramp test method is questioned, because the prescribed contaminants (soap solution and motor oil) are normally not representative for the commonly observed contamination. E.g. in Great Britain the test is only made with clean water as contaminant, and with a standardized footwear, thus not barefoot. At the interpretation of available test report, one has to check care-

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**Fig. 5. The HSL DIN ramp coefficient of friction test [1]**
*Rys. 5. Stanowisko do oznaczania współczynnika przeciwpoślizgowości posadzek na rampie DIN [1]*

**Table 4. Classification of skid resistance according to DIN 51130**
*Tabela 4. Klasy odporności na poślizg wg DIN 51130*

| Class | Inclination angle of the ramp [°] |
|---|---|
| R9 | 3 – 9 |
| R10 | 10 – 19 |
| R11 | 19 – 27 |
| R12 | 27 – 35 |
| R13 | > 35 |

fullywhich testing procedure was exactly used, and if the used testing procedure is relevant enough for the real circumstances in which the flooring is used.

**Measuring coefficient of friction on the site.** Mobile or portable instruments are applied to measure CoF on the site, on the flooring before or during use. Numerous related assessment methods exist, but the basic principle is most clear in the elementary slip meter (Figure 6). This horizontal slip meter is moved manually, and during the movement the force needed to drag a standardized foot (steel cylinder with standardized coating on the sliding face) is measured or recorded. In this way the

**Fig. 6. Elementary slip meter for horizontal surfaces [9]**
*Rys. 6. Urządzenie do pomiaru poślizgu na powierzchniach poziomych*

static as well as the dynamic coefficient of friction is measured. This instrument complies with ASTM C-1028. The coefficient of friction μ is easily calculated from the relation between the measured pulling force and the weight of the drag foot. Different drag feet are available for different floor systems. Mostly the coefficient of friction of the dry floor is measured with this method.

More sophisticated versions of this elementary apparatus are on the market, such as the Floor Slide Control 2000 (FSC 2000) and the Burngraber Portable Slip Tester [7]. However, these instruments are not frequently used. The measuring principle is schematically represented in Figure 7. As an illustration, two commercially available versions are shown in Figure 8a and b. The instrument moves automatically over the floor and drags a small foot (Figure 8a), or via a carriage the foot is dragged over the floor over a certain distance (Figure 8b). The foot can be

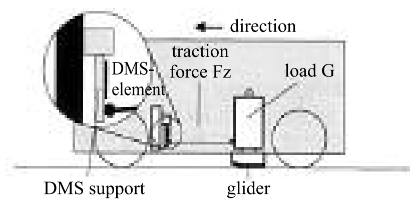


**Fig. 7. Principle of a mobile friction meter (DMS = strain gauge)**
*Rys. 7. Zasada działania mobilnego urządzenia do pomiaru poślizgu (DNS = czujnik odkształceń)*

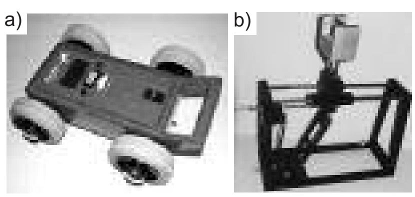


**Fig. 8. Australian apparatus (a); burngraber apparatus (b) [10]**
*Rys. 8. Handlowo dostępne urządzenia do pomiaru poślizgu: a) przyrząd „australijski", b) przyrząd Burngrabera*

provided with different types of soling. The drag force needed is recorded, e.g. in the apparatus of Figure 8a by means of a strain gauge glued on a small beam that is bent by the drag force. When the beam is bent, the electrical resistance of the strain gauge changes, and this change can be related to the force applied by the dragged foot. The relation between the friction force and the weight of the foot gives the friction coefficient. These methods provide the static as well as the dynamic coefficient of friction. An additional advantage is that comparative measurements can be made at different locations and at different times. Universally accepted criteria to decide if a floor is sufficiently rough are not yet agreed for these apparatus. E.g. the Dutch Railway company applies its own criteria: for areas with higher slip risk such as stairs and areas where travelers change direction, the friction coefficient must be at least 0,44 for rubber and plastic soling (measured dry and wet) and 0,33 for leather soling (only dry) [10]. In principle, the slip resistance measured on the site with a mobile instrument cannot be related to the ramp value of friction, and vice versa.

## Experimental investigation of skid resistance of concrete industrial floor

**Problem statement.** In the case under consideration, the operators indicated several zones of an industrial concrete floor, which they experienced to be slippery and non-slippery [8]. The question was asked what the causes were of this difference. Based on subjective experience of the users 4 zone types were distinguished:

- type 1: no traffic, no cleaning (under racks);
- type 2: no traffic, cleaned;
- type 3: forklift traffic, cleaned, slippery;
- type 4: torklift traffic, cleaned, stiff.

**Surface roughness measurements.** Cores were drilled out of the concrete floor in the different zones. The roughness parameter was determined for 6 different directions over the core surface. The values are presented in Figure 9. The values are the lowest

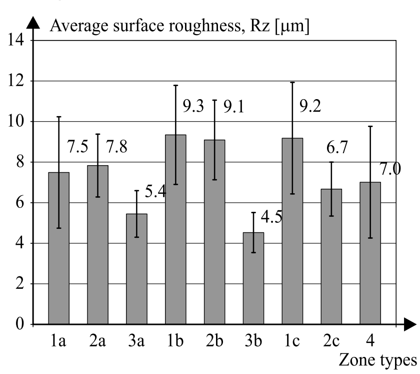


**Fig. 9. Average values Rz for 4 types**
*Rys. 9. Średnia wartość wskaźnika Rz czterech typów powierzchni*

for type 3 conditions (traffic, cleaned, slippery). This coincides with the feelings of the users. However, all the values are rather small, as compared to the values given in Table 2, indicating that all zones have high to moderate potential to slipperiness. The roughness values for type 4 are higher than for type 3, but lower than for type 1 and 2, where no traffic took place. This means that forklift traffic could not be the reason for the different behaviour and slipperiness sensation of type 3 zones. Therefore, further microscopic investigations were carried out.

**Optical Microscopy.** The surface of the cores was examined with an optical microscope Olympus B061. The surfaces of some cores showed a homogeneous colour, without visual colour differences (Figure 10). Some other cores showed two well observable phases, light and dark (Figure 11). No roughness differences could be observed by optical microscopy. No correspondence could be found between visual aspect, roughness or observed slipperiness.

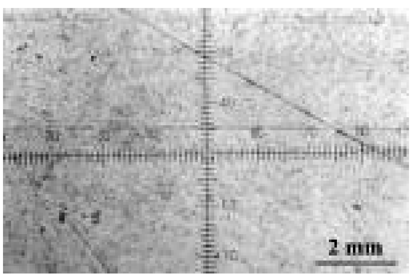


**Fig. 10. Surface of type 3 (core 3a) – dark phase in light matrix**
*Rys. 10. Powierzchnia typu 3 (próbka 3a) – ciemne fazy w jasnej matrycy*

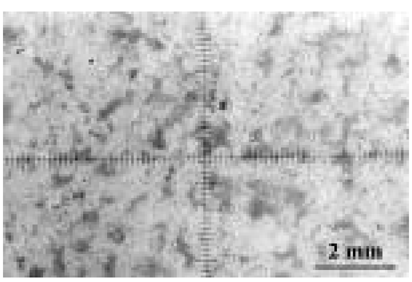


**Fig. 11. Surface of type 4 (core 4) – shows two well observable phases**
*Rys. 11. Powierzchnia typu 4 (próbka 4) – ciemne fazy w jasnej matrycy – dwie wyraźnie rozróżnialne fazy*

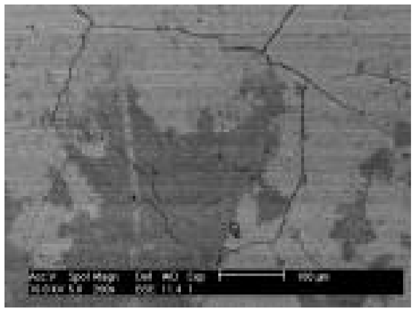

**Fig. 12. BSE analysis of core 3a (magnification 200x): large, dark zones**
*Rys. 12. Analiza SEM (BSE) powierzchni próbki 3a (powiększenie 200x): duże, ciemne obszary*

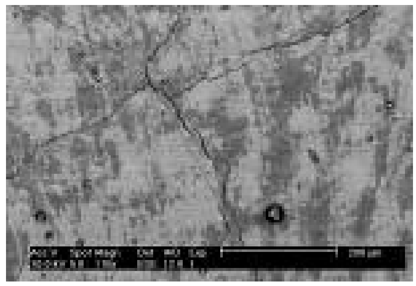

**Fig. 13. BSE analysis core 4: minor dark zones, with preferential orientation**
*Rys. 13. Analiza SEM (BSE) powierzchni próbki 4: drobne ciemne obszary o uprzywilejowanej orientacji*

**Scanning electron microscopy.** Using a Philips XL 30 FEG Scanning Electron Microscope the surfaces of type 3 (Figure 12) and type 4 (Figure 13) were examined in back scatter mode BSE. With this procedure the reflected electrons are detected. They give an idea of the composition of the surface. Zones with heavier atoms are characterized as lighter zones, zones with lighter atoms as darker zones. The BSE analyses were complemented with microanalysis EDX, in which X-rays are detected who indicate the atomic composition of the surface. The dark zones show a high concentration of carbon atoms, probably originating from cleaning products, tires, residue of curing products. However, it is actually impossible to determine what the exact origin is of the carbon in the dark zones.

## Conclusions

Roughness measurements allow the classification of the surface of the industrial concrete floor as having high or moderate potential for slipperiness. However, it still remains very difficult to determine the exact causes of slipperiness, for which people seem to be very sensitive. Actual standards may be able to allow classifications of slipperiness, even in contaminated conditions, but the inverse problem of determining the real causes of slipperiness in an actual case must still rely on long term testing on the site.

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