ANALYSIS OF THE SLIP RESISTANCE OF CERAMIC SURFACES BY DIFFERENT METHODS

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ABSTRACT

Ceramic tiles can be used outdoors and, therefore, may be exposed to moisture, which requires that the tiles have features that ensure pedestrian safety when walking. The safety is measured indirectly by the coefficient of friction. There are different methods for determining slip resistance but there is no worldwide consensus on standardizing just one method. This fact causes difficulties for manufacturers, suppliers and customers, as it poses many doubts and different interpretations of possible uses for the same product. In this work, nine ceramic tile surfaces were evaluated using four different slip resistance methodologies: Tortus, BOT, Pendulum and Ramp. Repeatability

analysis was performed to evaluate the coefficient of variation of each method and correlation analysis was performed to determine the sensory evaluation of pedestrians for each of the nine surfaces studied. Among the evaluated methods, the Pendulum is the one that showed the lowest variability in the dry and wet conditions because the coefficient of variation of the Pendulum test was much lower in comparison to those of the Tortus and BOT methods. In the sensory evaluation, the Pendulum method also showed a good correlation, with Pearson's coefficient of 0.946. The ramp method also performed well with a coefficient of 0.970. The Pendulum proves to be the best method to be adopted as a standard in terms of repeatability and reproducibility of measurement in real conditions.

1. INTRODUCTION:

Ceramic tiles are widely used as flooring in both residential and commercial environments, including outdoor areas, called wet areas, and in these specific situations the tile must have some slip resistance (NBR 15575: 2013). This is one of the major difficulties encountered by the ceramic tile industry, as in most cases problems related to falls and slips are attributed solely to the tile surface. Data showed that workplace accidents involving slips and falls in the United States are among the three most costly in the country, with an annual cost of US$ 11.2 billion, or 19.2% of total costs (LIBERTY MUTUAL WORKPLACE SAFETY INDEX, 2018). Reports from Asian countries estimate that in 2010 about 8.5 million people sought emergency rooms due to slips/falls (CHEN et al., 2015). Slip and fall accidents cost about £ 1.43 billion a year in England (ENGLAND HEALTH AND SAFETY EXECUTIVE, 2017).

Friction is widely used as an indicator of slip resistance on floors (CHANG; HIRVONEN; GRÖNQVIST, 2004). Measurement of the coefficient of friction is one of the main approaches in the evaluation of slip resistance (LECLERCQ; TISSERAND; SAULNIER, 1995), (CHANG et al., 2001), (GRÖNQVIST et al., 2001). Adequate slip resistance of floor coverings is a prerequisite for safe walking, but the incidence of slip and fall indicates that insufficient slip resistance is a problem that often arises. This insufficient slip resistance may be due to inadequate material on the floor surface, or it may be caused by surface wear or lack of maintenance (DERLER et al., 2015).

It may be noted that the coefficient of friction between two surfaces is an indirect measure of slip resistance. However, it should be borne in mind that the coefficient of friction depends on both the fixed surface (the floor covering) and the sliding surface (the sole of the footwear). In addition, anthropodynamic factors may occur, such as the presence of materials or substances between these, such as sand, water, oil, soap, etc. (KIM; PARK; KIM, 2018), (DEMARCH et al., 2019). In many cases, slips and falls can be attributed to floor coverings with insufficient slip resistance. Although liquid or solid contaminants may contribute to slippery conditions, the critically low coefficient of friction between the pedestrian foot and the flooring is fundamentally linked to the material and surface properties of the floor (CHANG et al., 2001), (KIM; HSIAO; SIMEONOV, 2013).

Numerous different devices have been developed to perform coefficient of friction measurements. They use traction, torque, energy loss or the inclination angle to determine this characteristic (GRÖNQVIST; HIRVONEN; RAJAMÄKI, 2001). The currently most widely used portable test devices have been categorized based on their operating principle: drag or tow system, pendulum, articulated arm and locked wheels. But none of them use real footwear when assessing surface slip resistance (GRÖNQVIST

HIRVONEN; RAJAMÄKI, 2001), (ASCHAN et al., 2005). Instead of wearing shoes, portable slip testers often use special sliding materials to assess slip resistance (ASCHAN et al., 2005).

Many studies relating the coefficient of friction to roughness parameters obtained through contact profilometry and optical analysis have been developed (ENGELS, 2018), (UK SLIP RESISTANCE GROUP, 2016). On the other hand, the Brazilian (NBR 13818: 1997), American (ANSI A 137.1 of 2012), German (DIN 51130 of 2004) and Australian (AS 4586 of 2013) standards use devices that are based on the contact between a standardized rubber and a test surface to measure the coefficient of friction between the two surfaces and do not relate slip resistance to roughness. It is not yet clear which form is most efficient for assessing the slip resistance of a surface.

Although many different types of friction measuring devices have been developed, there is no universally accepted device and testing method (KIM, 2012). Studies have shown great disagreement about the results of these devices, even using the same floor conditions and contaminants (DEMARCH et al., 2019), (RICOTTI; DELUCCHI; CERISOLA, 2009), (GRÖNQVIST; HIRVONEN; TOHV, 2000), (HARRIS; SHAW, 1988).

Given the difficulty in identifying which method is more consistent, this study aims to evaluate which of the methods – NBR 13818 (similar to ISO 10545), ANSI A 137.1 and AS 4586 – shows greater repeatability in terms of results and better reproducibility of the actual conditions of use perceived by users, so that specifications of use could be carried out as accurately as possible. The analyses were made by testing nine ceramic surfaces with different characteristics and finishes. The repeatability was determined by the coefficient of variation of each method. The results given by each apparatus/method were compared with the practical evaluation performed by a set of users.

2. MATERIALS AND METHODS:

In order to compare different methods of measurement of the coefficient of friction, eight ceramic products with different surface finishes were selected for this study. The tested surfaces are shown in Table 01.

Typology	Surface Finish
Glazed monoporosa	Glossy
Glazed porcelain tile	Polished Satin Covered with corundum Covered with grits
Technical porcelain tile	Polished Natural Natural with decoration

Table 01. *Tested ceramic surfaces*

To compare the repeatability of the currently adopted methods, 132 samples from each of the 8 selected surfaces were evaluated. The tests were performed according to the following standards: NBR 13818 (similar to ISO 10545), ANSI A 137.1, AS 4586 and DIN 51130. For the tests according to NBR 13818, Brazilian standard, the Gabrielli DS Dynamic Slip device was used. In the tests according to ANSI A137.1, the BOT tribometer of Regan Scientific Instruments was used. For tests according to AS 4586, Australian standard, the Munro digital pendulum was used. The tests with the ramp were performed with a Gabrielli device, with an adaptation: besides performing the oil test on its surface, a water test was also performed. The tests were performed in dry and wet conditions, according to the methods described in the standards. The tests were repeated 5 times with each apparatus except the ramp test.

The variability of the methods, except for the ramp, was analyzed by the coefficient of variation. It was not possible to perform the evaluation by standard deviation because the Pendulum uses different values of BOT and DS (Dynamic Slip). The slip resistance test consisted of forming a 500 mm × 3000 mm flat track with each surface. The track was cleaned with flannel and commercial ethyl alcohol. A stream of water flowed over the surface of the track and a person walked barefoot over the wet track. It was decided to perform the test with bare feet to eliminate the possible variability of the footwear. The test was performed by three different people who established a sliding resistance scale of the tile surfaces, ranging from the least resistant, which offered the least safety, to the most slip resistant. Correlation analysis was performed between the scale established by users and the results measured with the three devices using the three methods already mentioned.

3. RESULTS AND DISCUSSION

The following figures show the coefficient of variation of the tested methods, DS (Dynamic slip), BOT and Pendulum for each tile surface typology. Figure 01 shows the coefficient of variation of the Satin surface with the different methods used to determine the coefficient of friction.

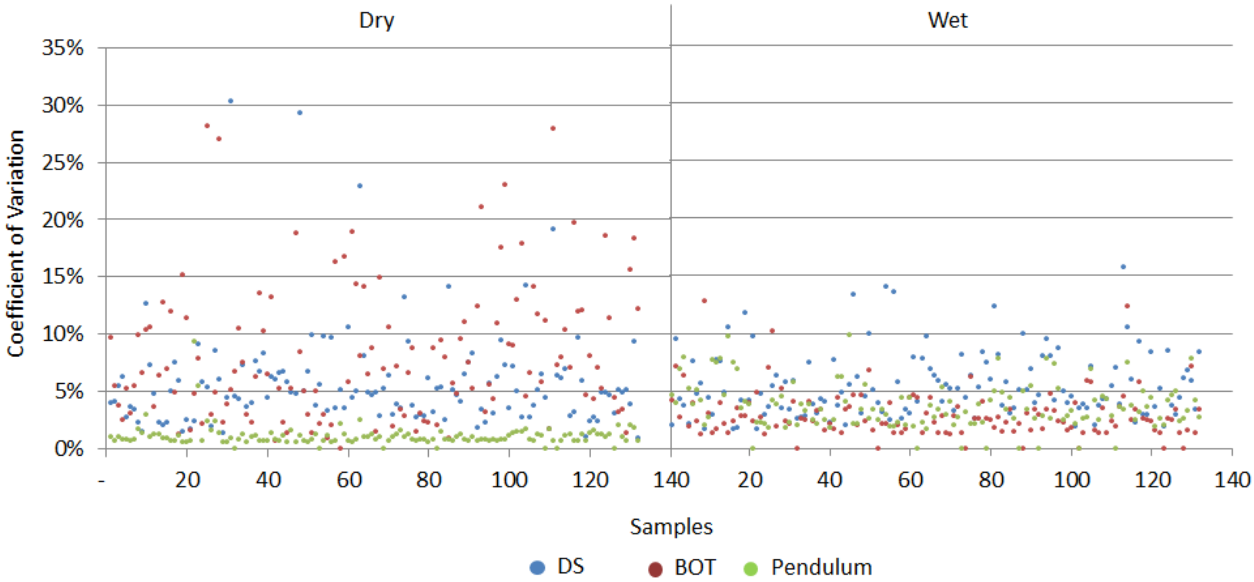

Figure 01. *Variability of measurement: Satin surface*

According to the graph in Figure 01, in the dry condition the results for the DS Dynamic Slip and BOT systems showed high variability due to their high coefficient of variation. The Pendulum method showed very satisfactory results, since its coefficient of variation is less than 5%. In the wet condition, the Pendulum method showed higher variability when compared to the dry condition, very close to that of other devices/methods.

Figure 02 shows the variability of the test results performed with the natural surface. The Pendulum showed less variability when compared to the DS Dynamic Slip and BOT systems. The same also occurred when comparing the dry and wet conditions, since in the dry condition the variability of the Pendulum system was lower. BOT presented higher variability in the dry condition and DS Dynamic Slip in the wet condition.

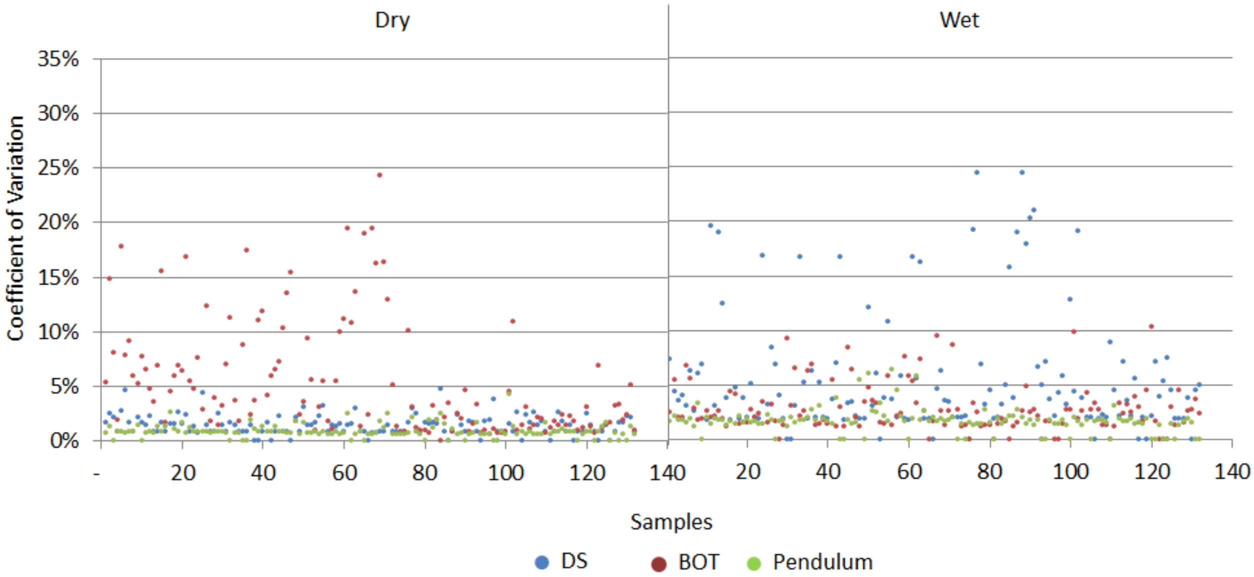

Figure 02. *Variability of measurement: Natural Surface*

Figure 03 shows the variability of measurements on the polished technical surface. A very interesting situation is observed because, unlike the other surfaces, the Pendulum showed great variation in the wet condition. In the dry condition, the Pendulum continued to show less variability when compared to the others. This situation can be explained by the fact that this surface showed much lower results, especially in the wet condition, when compared to the other surfaces. Possible problems in the preparation of the rubber may have influenced the variability of the results. In addition, because these are low values, small variations will result in a large coefficient of variation. The behavior was very similar on the Glossy and Polished Glaze surfaces, as they are also very smooth surfaces.

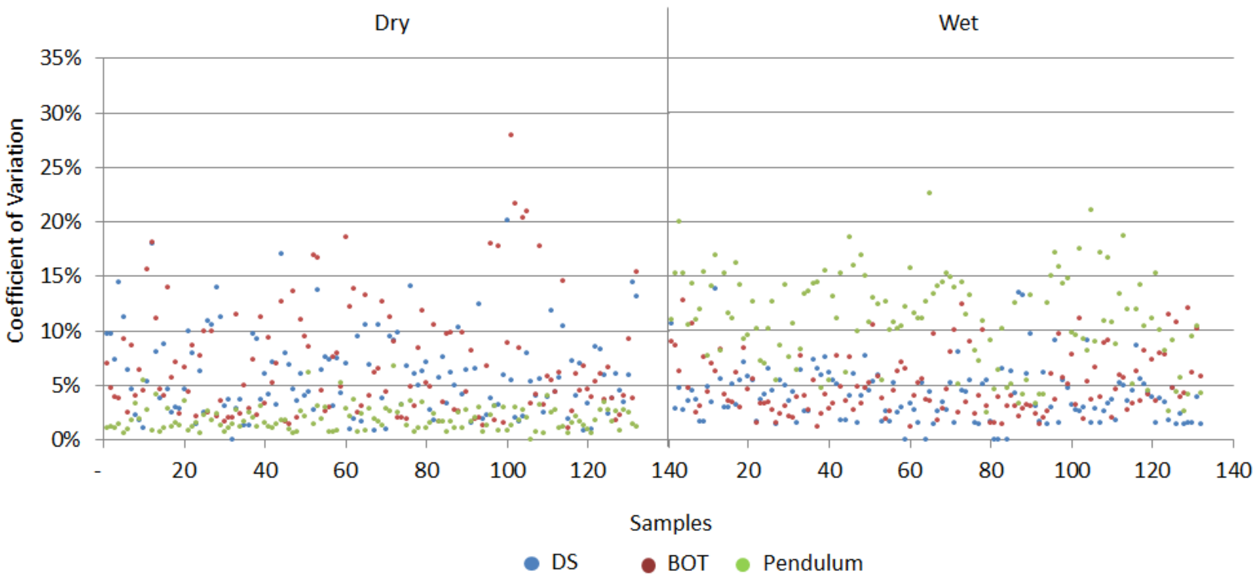

Figure 03. *Variability of measurement: Polished Technical Surface*

Figure 04 shows the variability of the corundum-coated surface. On this surface, the Pendulum method once again showed less variability in both dry and wet conditions. The BOT system showed higher variability in the dry condition and DS Dynamic Slip method in the wet condition.

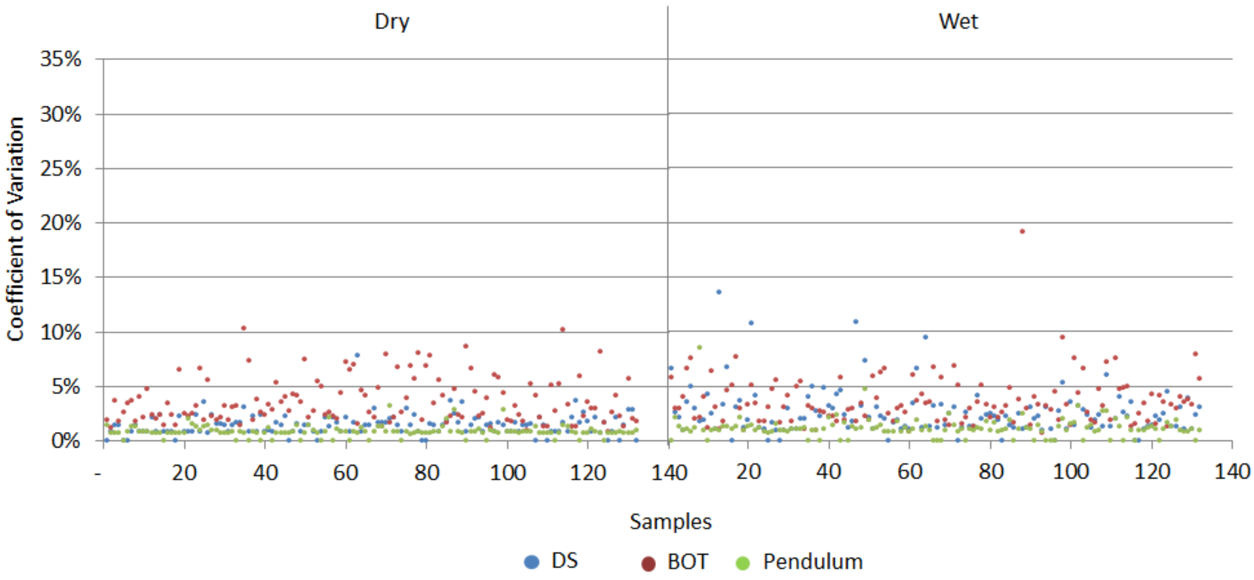

Figure 04. *Variability of measurement: Corundum Surface*

Figure 05 shows the variability of the grit surface. The Pendulum method showed satisfactory results in both dry and wet conditions, with a coefficient of variation of less than 5% in both cases.

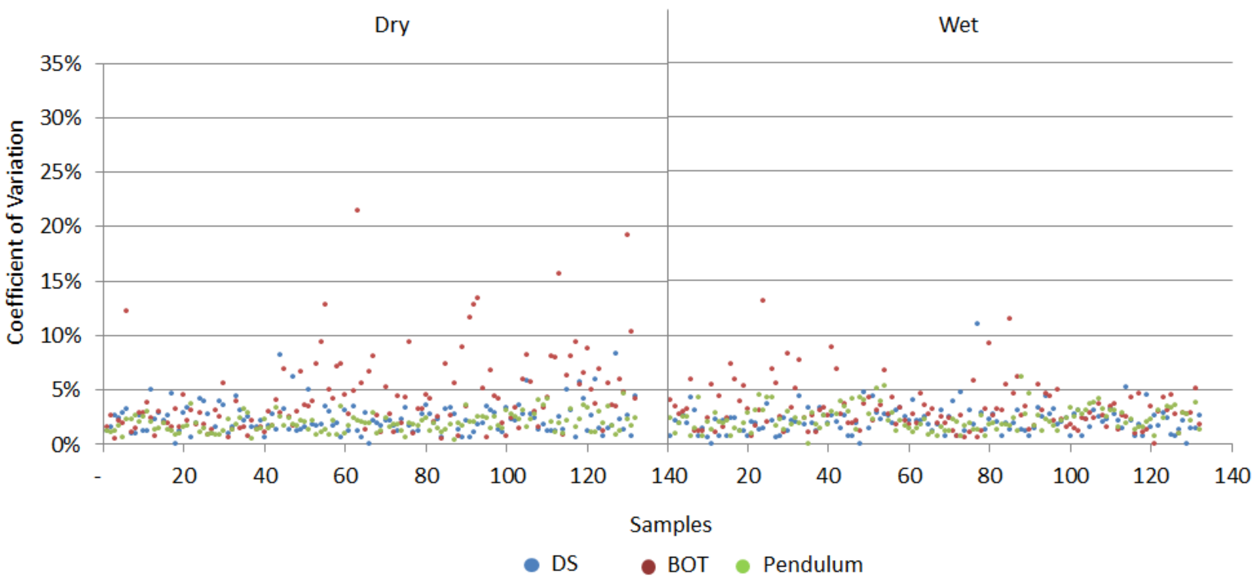

Figure 05. *Variability of measurement: Grit Surface*

Analyzing the results, it was observed that, among the tested methods, the Pendulum is the one that shows the best performance when the criterion is repeatability of the results in the same sample, except for the smoothest surfaces, where Pendulum variability was slightly higher. In the dry condition, the Pendulum was the method that showed the smallest variation in all tests performed, for all surfaces tested. In the wet condition, the Pendulum also showed excellent performance; however, on the smoothest surfaces, it showed great variation, as previously discussed.

The DS Dynamic Slip and BOT methods showed problems during the test run that are related to the shaking movements that the cart undergoes along the test surface. These movements are visually perceived and occur especially on smoother surfaces such as polished, glossy and satin. Therefore, it is quite reasonable to consider that these movements increase the variability of the test results.

Table 03 shows the relationship between the safety scale established in practical test by users and the results of tests with each surface in each of the analyzed methods. The relationship was established using the Pearson coefficient: the closer to 1, the stronger the correlation between two variables. The wet Pendulum and Ramp were the methods that best correlated with the safety scale, with a Pearson's coefficient of 0.946 and 0.970 respectively, very close to 1, showing that, in fact, the higher the coefficient of friction, the higher will the surface slip resistance be.

	DS		BOT		Pendulum		Ramp		
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Oil
Safety Scale	0.402	0.857	0.820	0.870	0.578	0.946	0.865	0.970	0.913

Table 03. *Correlation Analysis Matrix between Friction Coefficient and Safety Scale*

4. CONCLUSIONS:

The results of this study show that the Pendulum is the device/method that has the lowest variability in the majority of the tested surfaces, both in dry and wet conditions. On the other hand, the DS Dynamic Slip and BOT methods displayed the worst performance. The lowest variability was verified for the Pendulum test since the coefficient of variation of the tests performed with this method was much lower than those in the other tests, except for very smooth surfaces.

In the evaluation of the relationship between the result found with the device and slip resistance in practical condition, the Pendulum test was also the method that exhibited the best relationship, with Pearson's coefficient of 0.946, along with the Ramp test that presented a Pearson's coefficient of 0.97. However, the Ramp method has the disadvantage of not allowing on-site testing and the large number of samples required.

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