COMPARATIVE STUDY OF METHODS FOR SIMULATING WEAR IN ACTUAL SERVICE CONDITIONS

G. Silva[(1)], A. Muñoz[(1)], A. Beltrán[(1)], R. Domínguez[(1)]
A.M. López[(2)], M. Bañuls[(2)]

[(1)] **Instituto de Tecnología Cerámica (ITC). Asociación de Investigación de las Industrias Cerámicas (AICE). Universitat Jaume I. Castellón. Spain.**

[(2)] **LEROY MERLIN ESPAÑA, S.L.**

1. RESUMEN

The current European Regulation on Construction Products, Regulation (EU) No. 305/2011, continues to maintain the approach held in the previous Construction Products Directive (89/106/EEC), which considers durability as an essential requirement and seeks an equivalent form of assessment for any product that may be used for any particular purpose (e.g. Mandate M/119 “Floorings”). To that end, it encourages the development of testing standards through horizontal technical committees (e.g. CEN/TC 339 Slip resistance of pedestrian surfaces – Methods of evaluation), made up of experts on different types of materials.

In floorings, resistance-to-wear is one of the main characteristics to be taken into account in order to guarantee the absence of any change in appearance or loss of other functional performance features over an economically reasonable period of useful life. However, each type of flooring (ceramic, vinyl, laminate, stone, painted, polymer, etc.) uses specific test methods that are not comparable to each other and which are geared in most cases to establishing a scale for comparison within each range of products rather than to simulating how those products behave under actual service conditions.

The work presented here analyses the ability of different available test methods to simulate actual wear by pedestrian traffic by comparing them with the results of a field study in actual conditions of high pedestrian traffic and in respect of the new draft ISO/NP TS 23051 standard currently being developed by the international ISO/TC 189 Ceramic tiles committee.

2. INTRODUCTION

The continual progress made in ceramic tile manufacturing technologies has led to the appearance of numerous types of flooring, both in regard to design and performance features, which means they can be used in an equally wide range of settings, which nowadays include spaces requiring very high standards, both indoors (e.g. airports) and outdoors (e.g. street paving).

Similarly, other types of flooring have diversified in the way they are applied and are now a viable alternative in the refurbishment of indoor floors for light commercial and domestic levels of use, where prominently resilient flooring (PVC) has progressively increased its market share in recent years, to the detriment of textile floor coverings.

In such an ambience of multiple usage and diversity of floor types, it is becoming increasingly necessary to have regulations or guidelines on the use of these products, with technical information available to users and specifications writers that helps them to choose the most appropriate materials for their needs with the guarantee of economically reasonable durability.

Previous studies carried out on ceramic floors in actual service conditions [1, 2] confirm that surface wear is the main deterioration factor conditioning flooring durability. However, the test standards used for most materials to evaluate this particular feature do not allow simulation or do not assess the changes observed during actual use of the flooring, so that the recommended uses listed in commercial product data sheets are not comparable among each other nor can they be guaranteed.

In order to enable a reliable choice between different products, this study compares and assesses different wear resistance-testing methods and their ability to simulate changes in actual service conditions.

3. ANALYSIS OF WEAR TEST METHODS

After reviewing the regulations concerning the main types of floorings, it was found that great disparity exists in regard to both the wear mechanisms and evaluation criteria used (see Table 1).

Type of flooring	Method (standard)	Abrasive elements	Maximum intensity (cycles)	Thickness removed* (microns)
Ceramic	Surface abrasion (ISO 10545-7)	Steel and corundum balls	12000	~ 40
	Conservation of the decoration (Cahier 3778_V3 Annexe 10)	Steel wheel with no abrasive	22320	~ 35
	Wear by pedestrian traffic (ISO/NP TS 23051 - UNE 138001 IN)	IRHD 96 rubber and quartz	10000	~ 25
	Deep abrasion (ISO 10545-6)	Vertical steel disc and corundum	150	~ 900
Natural stone	Deep abrasion (UNE-EN 14157)	Vertical steel disc and corundum	75	-
Resilient	Wear layer thickness (ISO 20326)	Self-declaration on kind of use (no evaluation by means of wear tests)		
Laminate	TABER method (ISO 24338)	Steel wheels and corundum	8500	~ 250
** Maximum result obtained on porcelain tile samples*				

Table 1 *Analysis of wear assessment methods according to type of flooring*

The international standard for ceramic tiles includes two test methods, applicable to glazed or unglazed tiles respectively. For unglazed tiles, deep abrasion is evaluated using a steel disc and corundum, a method that causes scoring tracks about 1 mm deep and does not therefore enable the changes in surface appearance that are evident during actual use of the flooring to be simulated. For natural stone and stone agglomerates, similar test methods to the one for deep abrasion are used and which do not enable service life to be estimated either.

In resilient floors, in which the decoration is protected by an organic coating called the "wear layer" (between 0.15 and 0.7 mm thick), the "classification for level of use" (from Class 21 Light Domestic to Class 34 Very Intense Commercial) is allocated without any testing and entirely on the basis of the thickness of that wear layer, so it is not possible to estimate their durability either.

For the rest of the methods, in principle aimed at reproducing mainly surface wear, Table 2 details aspects relating to the wear mechanism, evaluation criteria and levels of intensity of use.

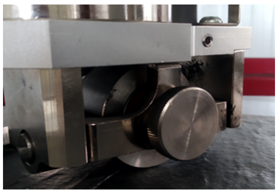
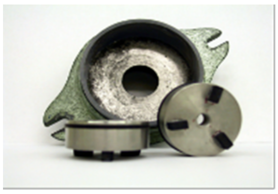
Standard	Device	Abrasive	Evaluation	Class according to use
ISO 24338		S-42 sandpaper Corundum 180 ANSI/CAMI D_{50}=78 microns	Loss of wear layer Does not assess changes in appearance	Domestic AC1 to AC3 Commercial AC3 to AC6
ISO 10545-7		Corundum FEPA 80 D_{50}=180 microns	Visible change of colour	Domestic 1 to 3 Public 4 & 5
Cahier 3778_V3 Annexe 10		No abrasive	Loss of decoration	Public U3 Moderate U3s Outdoor access U4 Intense
ISO/NP TS 23051		Quartz D_{50}=50 microns	Change in gloss Staining Visible change of appearance	Domestic L1 & L2 Outdoor access L3, H4 & H5 Outdoor H6

Table 2. *Analysis of wear conditions according to type of use*

For laminate flooring, two versions of the TABER method are applied that use abrasive wheels or corundum sand fed onto the surface, thus creating wear in a circular ring delimited by the travel of the wheels (Table 3). The test is continued until the "initial point of wear" is reached, this being the number of cycles needed to cross the wear layer, which can be detected by the disappearance of the decoration below that layer. Since it does not evaluate any changes in surface appearance until the wear layer is completely removed, this method is basically a less aggressive variant of the deep abrasion test and does not enable the service life of the flooring to be estimated either.

ISO 24338	ISO 10545-7	Cahier 3778_V3	ISO/NP 23051
			

Table 3. *Surface appearance of the samples at their classification limit stage*

The method that applies surface abrasion to glazed ceramic tiles uses a more aggressive abrasion system (steel balls and corundum) than actual service conditions, but the main drawback is that it only evaluates change in surface colour, which is why it has been widely questioned, as it gives misleading results that penalise matt, dark-coloured floors compared to glossy floorings with light colours.

Associated with this problem of excessive wear, a test method was developed within the context of the NF-UPEC certification to evaluate "preserved decoration"[3], applicable in the case of through body-coloured porcelain tiles. This method uses a steel wheel with no abrasive to evaluate the persistence of the decorative design, which, although it could be used as a resistance to rolling test, does not enable wear associated with the actual movement of people to be simulated either (Table 3).

In response to this problem, the Spanish UNE CTN 138 "Ceramic tiles" committee developed the method defined in Spanish standard UNE 138001:2008 IN [4], which is currently being assessed by the ISO TC 189 "Ceramic tiles" international committee as new draft international standard ISO/NP TS 23051. The method uses wear elements equivalent to actual usage processes (IRHD 96 rubber sole and D_{50} abrasive quartz = 50 microns), as well as a complete assessment process that includes surface changes observed in actual service conditions (gloss, stains and change of surface appearance). The method has been validated by field studies carried out under real conditions of use in commercial premises[2], where its ability to reproduce the changes in gloss observed in polished surface ceramic floorings installed in outdoor accesses was tested.

In addition to the above standardised methods, the accelerated wear method proposed by C J Strautins [5] as a means to assess changes in a floor's slip resistance is worth mentioning. The method is based on a Gardco unit used to test washability and wear in the paint industry, in which a horizontal linear slider drags scouring pads over the surface of the floor while alternating the direction it moves in. Given the deformability of the abrasive element, this method generates surface abrasion and could provide a viable alternative for simulating actual wear.

4. EVALUATION IN ACTUAL INDOOR SERVICE CONDITIONS

Prior to assessing surface wear test methods, a field study was initiated under actual conditions of indoor use. For this purpose, samples of resilient (PVC), laminate (LAM), ceramic (CER), multilayer wood (MLW) and marble (MAR) floorings were selected, thus covering the range of surface finishes commonly used in such environments and which included both matt and glossy surfaces (Table 4).

	60° gloss	85° gloss		60° gloss	85° gloss		60° gloss	85° gloss		60° gloss	85° gloss
PVC1	3.1	8.6	LAM1	8.8	10.5	CER1	96.2	96.3	MLW	76.7	86.0
PVC2	4.5	3.9	LAM2	6.6	4.7	CER2	96.5	99.3	MAR	94.9	98.0
PVC3	6.5	19.4	LAM3	7.1	11.8	CER3	3.6	2.0			
PVC4	6.7	17.1	LAM4	9.7	11.0	CER4	4.6	5.5			
PVC5	4.6	27.4	LAM5	5.2	5.2	CER5	11.1	17.1			

Table 4. *Samples used in the field study*

After an initial evaluation using the method described in ISO/NP TS 23051 to determine possible changes under actual conditions, a series of 12 samples were selected that covered all trends, i.e. with both increased and decreased gloss. After that, the floorings were installed in the middle of the aisle at the main self-service counter in the canteen of the Jaume I University (Figure 1). Given that traffic flows in a single direction and is limited by railings, optical counters were installed at the end next to the cash registers to count the number of people walking on the tiles under study. A non-adhesive installation system was used to enable the tiles to be removed and replaced so that any changes in the surface (colour, gloss, texture) could be measured using instruments in the laboratory.

Figure 1. *Evaluation in actual indoor service conditions. UJI canteen.*

During the follow-up of how gloss in the samples had fared, it was found that the most significant changes in matt tiles were detected in readings at an angle of 85° (5°

from the horizontal), whereas gloss loss in glossy tiles was more evident in readings at an angle of 60° and also these readings revealed less variability. Therefore, it was decided to use the angle for measuring gloss that best magnified change in each case so as to have a higher resolution with which to compare the results obtained in the lab. Figure 2 shows how the data evolved for both types of surface and measuring angles.

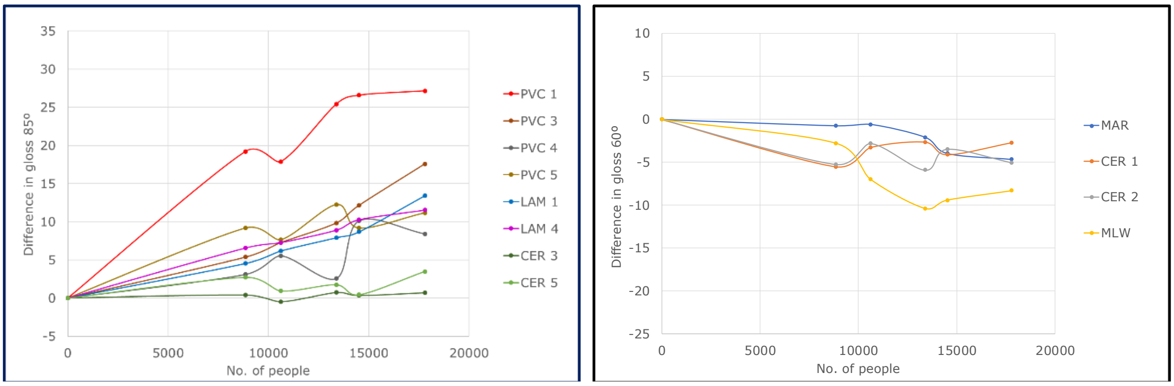


***Figure 2**. Evolution of floor coverings in actual service conditions*

5. STUDY OF LABORATORY SIMULATION METHODS

After discarding test methods whose mechanisms do not enable the wear observed in actual conditions to be simulated, it was decided to study the feasibility of using the ISO/NP TS 23051 method and Gardco unit to reproduce the changes observed in the field study. To do so, 6 floor coverings were selected, specifically 3 of each type of surface finish (matt and gloss), which exhibited the maximum, intermediate and minimum change in each type of surface.

The ISO / NP TS 23051 method is based on a modification of the procedure described in ISO 10545-7, in which the abrasive charge of steel balls is replaced with a cylindrical abrasion device with three rubber feet distributed symmetrically at angles of 120° and which uses quartz of D50=50 microns as abrasive, which is progressively proportioned as a function of the number of revolutions in each stage, as detailed in Table 5. After tests were carried out on all 6 samples, it was found that these test conditions were causing greater wear than had been observed in actual usage, with gloss being reduced in both matt and glossy surfaces, although the changes were much more significant in the latter (Figure 3).

Stage (revs)	125	250		500	1000	2500	5000	7500	10000
Sequence		Direct					Previous one + 2500 revs		
Proportioned amount (g)	0.12	0.25		0.50	1.00	2.50	2.50 each stage		

***Table 5.** ISO/NP TS 23051 sequencing and proportioned amount*

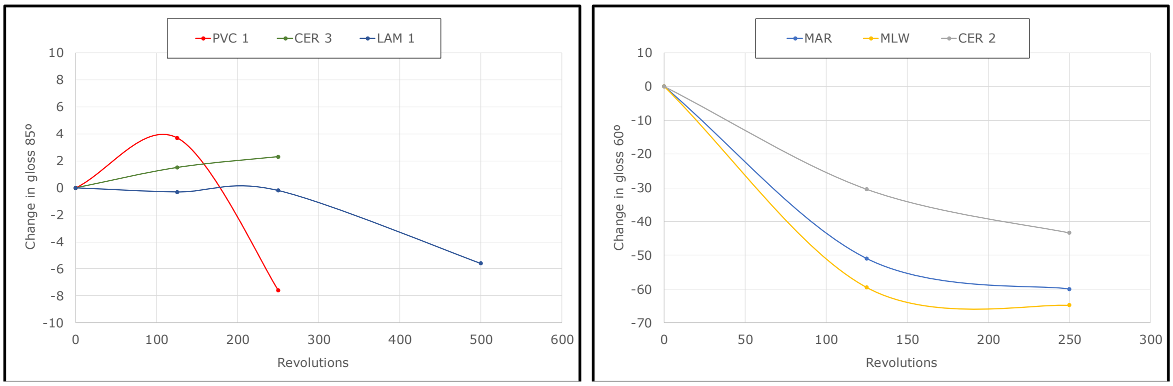


Figure 3. *Results of ISO/NP TS 23051 (initial stages)*

This method was developed and later validated with studies in actual conditions, as a means of reproducing wear at outdoor access points with heavy pedestrian traffic in which a constant presence of natural abrasives, and therefore a high level of aggressiveness, can be expected. Logically, the presence of abrasives inside premises with no direct outdoor exits (or with means to retain abrasives at entrances) should be much lower, which would justify the lower aggressiveness found in the study under actual conditions, which reveals high increases (resilient and laminated floors) and smaller losses (varnished wood) in gloss.

Therefore, it was decided to conduct a preliminary study on how the characteristics of the abrasive and the proportioned amount affected the outcome of ISO/NP 23051 TS testing.

5.1. INFLUENCE OF ABRASIVE PARTICLE SIZE

To verify the influence of abrasive particle size, comparative tests were carried out using two quartzes of equivalent chemical composition with average particle sizes of 20 and 50 microns respectively. For this purpose, successive stages were run in 25 cycles on samples of different materials, with a proportioned amount of 0.12g in each stage. As can be seen in Figure 4, the abrasive with the smallest average particle size produced the highest increases in gloss on matt surfaces and the lowest gloss losses, which confirms that wear mechanisms will be different in conditions of indoor and outdoor use and may even reveal opposite surface changes, as in the case of certain soft resilient floors (PVC 5), in which slight increases in gloss were seen in the indoor area of the enclosure while gloss was lost in areas leading directly outdoors.

5.2. INFLUENCE OF PROPORTIONED AMOUNT OF ABRASIVE

To analyse the influence played by the amount of abrasive present in the wear mechanism, D_{50}= 20-micron quartz was proportioned in varying amounts. For different types of matt surfaces, direct stages were carried out on a number of samples (125, 250 and 500 revs) with the progressive amounts set out in the ISO/NP TS 23051 method (0.12g, 0.25g and 0.5g). For the purposes of comparison, successive stages were performed on the same 125-cycle (0.12g) sample, reducing the amount of abrasive present in the second case.

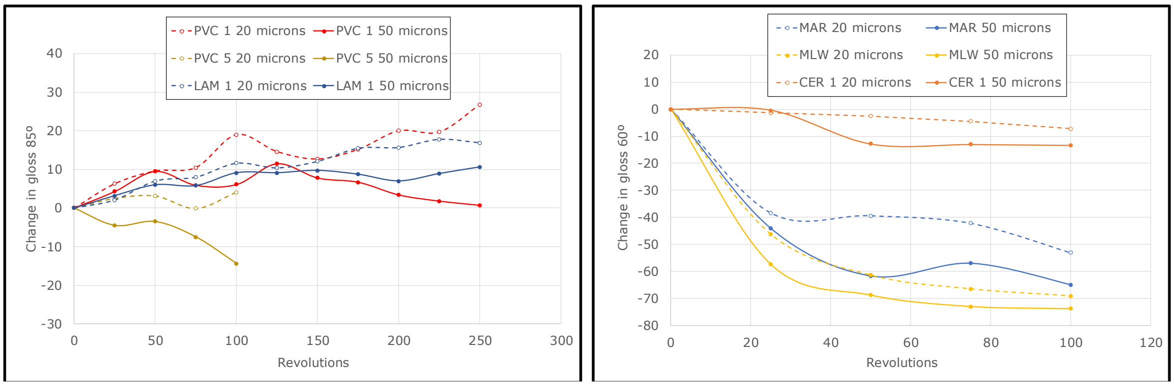


Figure 4. *Influence of abrasive particle size*

As can be seen in Figure 5, when more abrasive is used in the test (progressive proportioned amounts), the wear process tends to speed up, which in the case of low hardness floors (PVC 1 and LAM 1) reveals a turning point in the trend that initially increases the 85° gloss level. On the other hand, the use of smaller amounts of abrasive (0.12g) in successive stages leads to slower changes in gloss, although they reach higher absolute values, more similar to the changes observed in the study under actual service conditions.

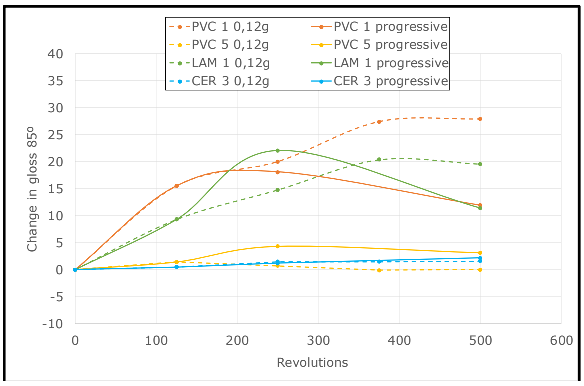


Figure 5. *Influence of the amount of abrasive*

5.3. WEAR SIMULATION TESTING IN THE LABORATORY

To carry out a simulation study of wear under indoor conditions, the only two methods that use wear mechanisms similar to actual usage were selected, namely the Gardco unit and the ISO/NP TS 23051 method, and the characteristics and proportioned amount of abrasive were adapted in the latter test according to the results presented above. Table 6 describes the test conditions used in each of the above methods.

The comparative study under actual service conditions was performed on 6 floorings - 3 with a matt finish (resilient, laminated and ceramic), and 3 with a glossy finish (polished marble, varnished wood and ceramic tile), thus covering the gloss variation ranges observed in actual conditions at both measurement angles (60° and 85°).

In Figure 6, the evolution of matt floorings under real-life conditions of use are compared to the laboratory results. As can be seen, there is certain consistency between the real-life data and the test results for the three types of floorings. It should be noted that the increase in gloss measured at an angle very close to the horizontal is not due to a reduction in surface micro-texture but to flooring loss of surface relief as it becomes progressively flatter, so that the reflection of the reflectometer light beam increases, as may be noted when the starting and worn topographies of the PVC 1 sample are compared (Figure 7).

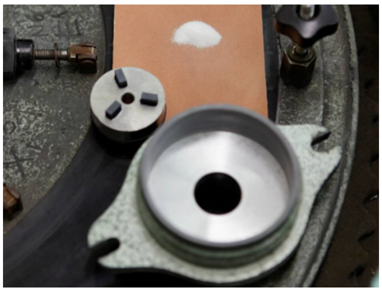
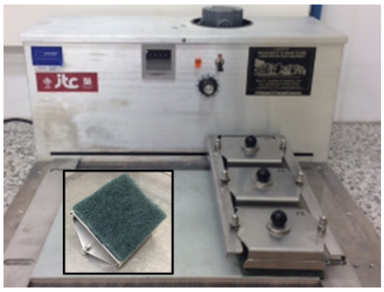
Test method	ISO/NP TS 23051 modified	Gardco D12VFI Washability and wear testing machine
Wear device		
Displacement	Multidirectional	Linear (both directions)
Abrasive material	Quartz D_{50} = 20 microns 0.12g every 125 revs	3M Scotch-Brite heavy duty scourer pad No. 86
Weight of the device	232 ± 2 g	1000 ± 50 g

Table 6. *Test parameters for wear simulation in indoor use*

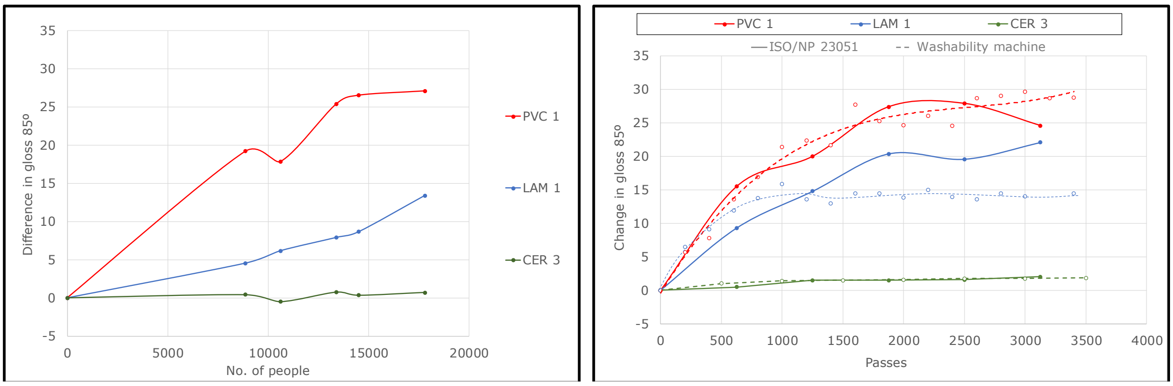


Figure 6 *Comparison of matt floors: Actual (left) & Laboratory (right)*

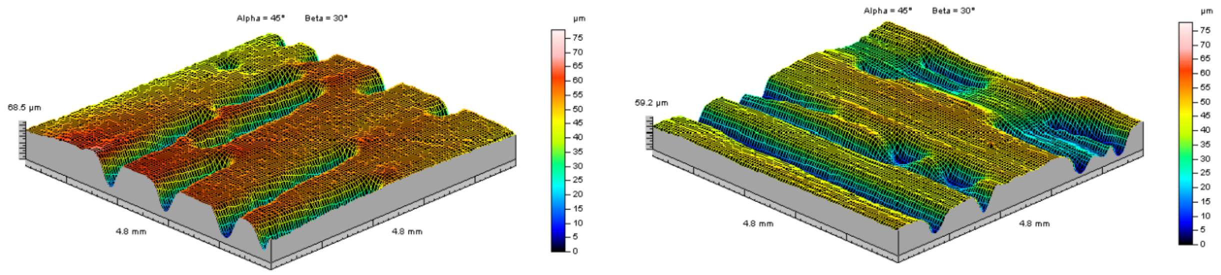


Figure 7 *Topography of the starting (left) and worn (right) PVC 1 sample*

This implies that both laboratory methods generate a wear depth similar to what occurs in actual service conditions and allow for conditions of indoor use in any type of matt flooring to be simulated.

However, the evolution of gloss measured at 60° on gloss surfaces cannot be correlated with actual service conditions, where reductions in gloss are very slight, while the loss measured in laboratory tests was significantly greater (Figure 8).

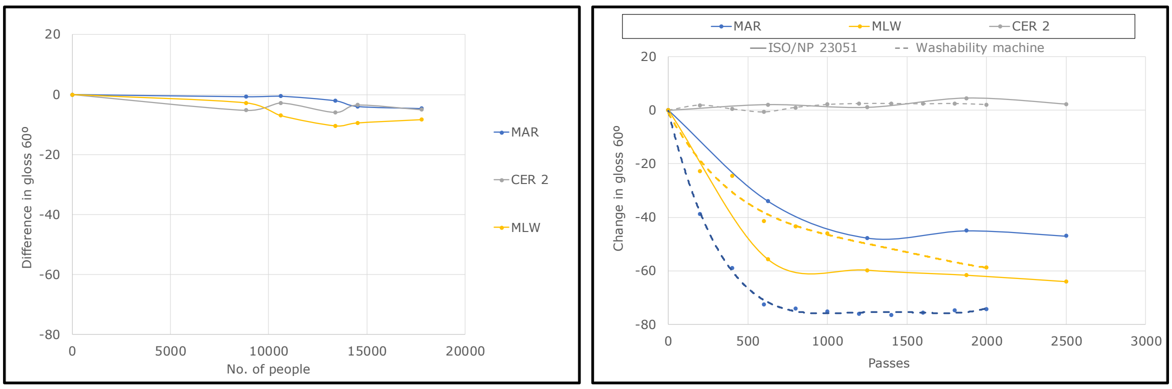


Figure 8. *Comparison of glossy floors: Actual (left) & Laboratory (right)*

These surfaces show no obvious correlation between the two lab test methods on the polished marble and varnished wood samples, while with the Gardco method, the varnished wood was found to be more resistant to wear than marble, a of this kind result that was reversed when the ISO/NP 23051 method was used. In surfaces with low roughness and low hardness, the wear-producing mechanism is quite likely to depend largely on the effective local pressure exerted by the abrasive particles on the smooth surface [6, 7], as this parameter clearly differs between both test methods as loose abrasive powder is used in one case and abrasive embedded in a scouring pad in the other.

6. CONCLUSIONS AND FUTURE ACTIVITIES

- Most test methods described in standards on products used as floorings resort to in-depth wear-producing mechanisms that are perhaps quite suitable for estimating the consistency and/or density of the material but do not allow surface changes associated with actual use of the product to be reproduced or its durability estimated.
- The pedestrian traffic wear-producing mechanism for conditions of indoor use is considerably less aggressive than was observed at outdoor exits, probably because of a smaller presence of abrasive materials and the smaller particle size of abrasive adhered to the soles of footwear. Therefore, different test parameters should be used to evaluate durability in either scenario.
- It was found that, by slightly adjusting the test parameters, the wear-producing method described in the draft version of ISO/NP TS 23051, already validated as a means of simulating wear in outdoor exit points, also enables changes in surface gloss in actual indoor service conditions of resilient, laminated and ceramic flooring to be reproduced.
- It is intended to continue this analysis of wear resulting from pedestrian traffic in actual indoor service conditions in order to define optimal test parameters that allow wear on any type of flooring to be reproduced.
- The findings of this study will be forwarded to the ISO/TC 189 WG1 Ceramic Tiles Test Methods so that the draft ISO/NP TS 23051, currently under development, can be further reviewed.

7. ACKNOWLEDGEMENTS

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