International Journal of Occupational Safety and Ergonomics
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tose20

Slip Resistance of Industrial Floor Surfaces: Development of an Elastomer Suited to In-Situ Measurement

Sylvie Leclercq[a] & Henri Saulnier[a]

[a] Working Life Department, French National Research and Safety Institute, Vandoeuvre France

Published online: 08 Jan 2015.

INTERNATIONAL JOURNAL OF
OCCUPATIONAL SAFETY AND ERGONOMICS 2001, VOL. 7, NO. 1, 93–102

Slip Resistance of Industrial Floor Surfaces: Development of an Elastomer Suited to In-Situ Measurement

Sylvie Leclercq
Henri Saulnier

Working Life Department, French National Research and Safety Institute, Vandoeuvre, France

Slips contribute to 12% of occupational accidents. A slip resistant floor is a mean to prevent slipping accidents occurring in workshops. Floor slip resistance is often evaluated by measuring a friction index, proportional to the force opposing slipping of a reference elastomer on the floor surface under test. When implementing a portable appliance, slip resistance measurements carried out on lubricated floors were not stabilized. The authors advanced the hypothesis of oil impregnating the elastomer. A new elastomer suited to in-situ measurement has been developed to achieve stable measuring conditions. This study highlights the fact that the nature and characteristics of a reference elastomer must be specified when slip resistance measurements are carried out.

slip resistance   floor surface   in-situ measurement   elastomer
slipping accident

1. INTRODUCTION

A study conducted in Sweden and covering all sectors of activity has evaluated the percentage of occupational accidents resulting from a slip at 12% (Strandberg & Lanshammar, 1981). Recommendations given after analysis of such accidents often include the wearing of antislip footwear and the installation of a slip-resistant floor finishing. This is why much of the

Correspondence and requests for reprints should be sent to Sylvie Leclercq, French National Research and Safety Institute (INRS), Working Life Department, Biomechanics and Ergonomics Laboratory, Avenue de Bourgogne, BP 27, 54501 Vandoeuvre Cedex, France. E-mail: <leclercq@inrs.fr>.

research work involving slip prevention relates to the methodology of measuring slip resistance (cf., e.g., Leclercq [1999], who provides a review of this work). Within the scope of this research, the accident situations studied involve slips occurring on soiled rigid floor finishings (covered with a more or less viscous product) or on ice, on which a person walks and slips when wearing town shoes, safety shoes, or safety boots. Such situations reflect the most hazardous conditions under which slips occur (Gronqvist, 1995; Strandberg, 1985; Tisserand, 1985).

A method of measurement for evaluating slip resistance of industrial floor surfaces in the laboratory has been developed at the INRS (Institut National de Recherche et de Sécurité, the French National Research and Safety Institute; Leclercq, Tisserand, & Saulnier, 1993a). This method allows a comparison to be made of slip resistance of new products on the market and a study of the effect of floor surface characteristics (e.g., roughness, permeability) on their slip resistance. More recently, a portable appliance developed in Sweden has been implemented for an in-situ evaluation of floor surface slip resistance (Leclercq, Tisserand, & Saulnier, 1993b, 1993c). With use, the slip resistance of floor surfaces in fact changes due to the different forms of chemical and mechanical attack to which these surfaces are subjected. With a portable appliance at our disposal, we can evaluate the actual situational slip resistance and study the effect of factors specifically linked to usage (fouling, cleaning, wear) on slip resistance. The complementary nature of the two (laboratory and field) methods of measurement has been explained in detail by Leclercq, Tisserand, and Saulnier (1994).

2. OBJECTIVES

Whether in the laboratory or in the field, slip resistance is evaluated by measuring a friction index, proportional to the force opposing slipping of a reference elastomer on the floor surface under test. When implementing the portable appliance, friction index measurements recorded in succession and under identical conditions for an oil-covered floor decreased significantly before stabilizing. The authors advanced the hypothesis of oil impregnating the elastomer and had to take this phenomenon into account when drawing up the measuring procedure for this appliance. Research into an elastomer that is less sensitive to this phenomenon has proved necessary to facilitate systematic use of this portable appliance. The purpose of the present paper is to present this work and its impact on the methodology of measuring slip resistance.

3. MATERIALS AND METHODS

Some of these experiments were presented in a past paper (Leclercq, Tisserand, & Saulnier, 1993b). Here we recall and supplement their results.

3.1. Description of Measuring Method

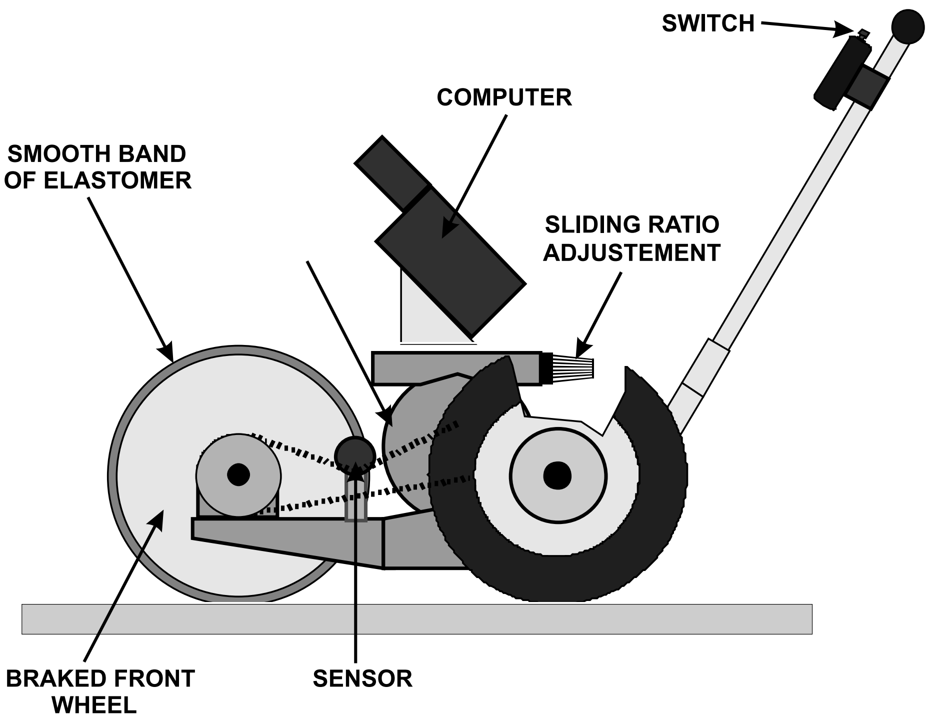

Figure 1. Portable appliance for measuring slip resistance of floor surfaces.

The measuring appliance shown in Figure 1 is pushed manually by the operator at constant speed (v). The operator selects start and end of measurement by means of a switch. The rear wheels of the appliance drive a reduction gear through a chain, the rotational speed of the front wheel is thereby reduced causing the latter wheel to slide on the floor surface to be tested. This 25×10^{-2} m diameter front wheel is clad with a 25×10^{-3} m wide, 5×10^{-3} m thick, smooth elastomer tyre. A friction force (Fd) opposing the sliding motion is thus induced at the interface between this elastomer and the floor finishing. The normal force at the interface between the elastomer and the floor surface is 112 N. The friction index (IdF), proportional to the force *Fd*, quantifies the slip resistance of the floor surface (*IdF* = *Fd* [expressed in N]/112). At the end of the measurement run, a computer informs the operator of

- the mean friction index and its standard deviation,
- the actual sliding ratio of the front wheel,
- the distance over which the floor finishing has been tested,
- the average displacement speed of the appliance.

Five successive measurement runs are carried out and the mean friction indices are averaged to assess the slip resistance of the lubricated floor surface.

3.2. Change in Slip Resistance Assessment

Measurements were initially taken on a rough floor surface abundantly covered with vegetable oil in order to work under reproducible lubrication conditions. Two test wheels clad with an elastomer (E1) by a tyre-fitter were used, one was new and the other had already been used for previous oiled floor measurements 1 year and 2 weeks before. The portable appliance was fitted with these two wheels in succession. The displacement speed of

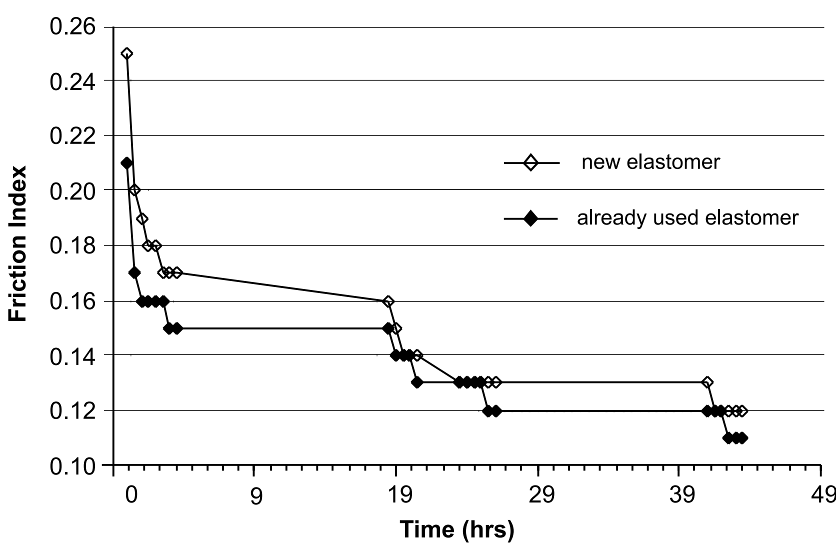

Figure 2. Change of slip resistance with time measured on a rough tiled surface using reference elastomer E1. Each evaluation represents an average value based on five successive friction index measurement runs (taken from Leclercq, Tisserand, & Saulnier, 1993b).

the appliance and the sliding ratio of the test wheel were set at 1 m/s and 50% respectively. Tests were conducted over a period of 3 days. A slip resistance evaluation was taken every 30 min over a distance of approximately 2 m using each of the two test wheels. Longer interruptions, sometimes a night, occasionally separated the measurement series. Figure 2 shows the results of these measurements and reveals a significant fall in slip resistance with time.

This change in slip resistance observed for elastomer E1 was also observed for elastomer E2, with which the test wheel was clad when the appliance was delivered, and for polychloroprene elastomer E3, usually used with the laboratory appliance intended for evaluating the slip resistance of samples of new floor finishings. The kinetics of slip resistance change is the same for all three elastomers, although the stabilized slip resistance value differs slightly.

3.3. Interpretation and Constraint in Relation to New Elastomer Development

It can be observed from Figure 2 that both initial and stabilized measurements are slightly higher for a new elastomer, which has never been in contact with oil. The fall in slip resistance is probably due to adsorption of oil by the elastomer. In fact, unlike the case of friction involving metals in which the lubricant/metal interface remains well defined, lubricated friction of elastomers causes a diffusion phenomenon at the contact between the lubricant and the elastomer. This diffusion forms an intermediate layer, whose properties depend on both the lubricant and the elastomer (Moore, 1972). It is therefore probable that at least the hysteresis component of friction, associated with the viscoelastic properties of the material, is modified in the case of lubricated friction (Moore, 1972). In this case, it may be assumed that the time required to reach a stable index for friction between the elastomer and the lubricated floor surface is linked to the time required for diffusion of oil molecules to occur over an elastomer depth (h) equal to the thickness of the layer deformed during friction by floor surface asperities. We took measurements using a new test wheel first on a smooth acrylic coating, then on embossed ceramic clay tiling, to check that the aforementioned time does indeed depend on the size of the surface asperities. It appeared that the friction index stabilized quicker on a smooth floor surface than on a surface featuring a raised design, but it is difficult to be categorical on this issue given the differences in the value of friction index and consequently in the size of the variation between measurements taken on a smooth floor surface and those taken on a floor surface featuring a raised design (Leclercq, Tisserand, & Saulnier, 1993b).

3.4. Repercussions on Measuring Procedure and Need to Develop a New Elastomer

To achieve stable measuring conditions, the test elastomer must be placed in contact with the relevant oil prior to slip resistance measurement. After an immersion time of about 20 hrs in vegetable oil, the measured friction index has stabilized. When people move about on soiled floor surfaces at a company, their footwear soles become impregnated in depth with this contaminant. We therefore consider these measuring conditions to be realistic.

The elastomer should be conditioned in oil, the reference lubricant, when undertaking measurement on new floors to assess its slip resistance in the most hazardous conditions. However, when evaluating the slip resistance of an industrial situation (more or less worn or soiled floor surface), conditioning of the elastomer in the product likely to be found on the company floor is indeed necessary. This preparation is tedious and this is why the INRS has had an elastomer developed at the LRCCP (Laboratoire de Recherche et de Contrôle des Caoutchoucs et des Plastiques, French Rubber and Plastics Research and Testing Laboratory), which is less sensitive to this phenomenon and therefore fulfils the aim of facilitating systematic use of this portable appliance.

4. RESULTS

4.1. Elements of the Specification for Elastomer E4 Designed for In-Situ Measurement of Floor Surface Slip Resistance

The engineering properties of the elastomer must be close to those of the material currently used for slip resistance measurements. The testing material must nevertheless allow measurement stabilization without preconditioning in the product likely to be encountered on the company floor.

Most often, these products are

- vegetable fats, organic fatty acids;
- lactic acid and animal fats;
- blood.

Next come

- cutting oil and mineral oil.

Finally, and very occasionally

- brine,
- sugar in solution,
- acetic or citric acids.

Based on this order of priority, the LRCCP identified firstly the basic elastomers that were the least compatible with the different fluids encountered. For this, measurements of swelling rate were taken after immersion in the different fluids for variable periods up to 24 hrs. After adjusting the engineering properties, new immersion tests were performed (LRCCP, 1997). The elastomer that performed best was then moulded around the rim of a test wheel in order to assess the stability of friction measurements taken with the portable appliance fitted with test wheel clad in this new elastomer.

4.2. Change in Friction Index Measurement

Friction indices are of low magnitude under lubricated conditions. Their measurement depends on many parameters (Leclercq, Tisserand, & Saulnier, 1995). For this reason, we took measurements using two types of elastomer (previously used elastomer E1 and newly developed elastomer E4) to compare changes in friction indices under absolutely identical conditions for the two elastomers. Measurements were taken on a rough floor surface abundantly covered with vegetable oil. The portable appliance was successively fitted with test wheels clad in elastomers E1 and E4. The appliance displacement speed and the sliding ratio were set at 0.4 m/s and 75% respectively. Tests were conducted over a period of 3 days. Slip resistance assessment was taken every 30 min over a distance of approximately 2 m using each of the two test wheels. Longer interruptions, sometimes a night, occasionally separated the series of measurements. Figure 3 shows measurement changes for each elastomer. It was obviously sufficient to carry out tests over a period of 2 days in the case of elastomer E1. Whereas slip resistance assessment taken using elastomer E1 fall sharply during the first day, assessments taken using elastomer E4 appear stable over the 3 days considered. Their average value is 0.59 and their standard deviation is lower than 0.01. Slip resistance variability over the 3 days is thus of the same order as that of the five successive friction index measurements taken at each moment in time considered. No monotonic change in slip resistance was observed during these 3 days.

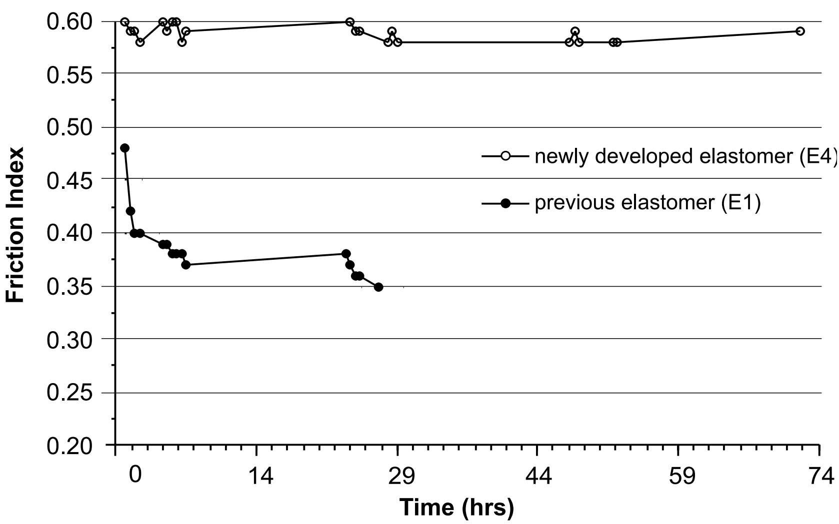

Figure 3. Change with time in slip resistance assessed on a rough tiled surface using two different reference elastomers. Each evaluation represents an average value based on five successive friction index measurements. Standard deviations calculated on these five measurements are less than 0.01 for both elastomers, except for one set of measurements carried out with elastomer E4 for which standard deviation is equal to 0.02.

5. DISCUSSION AND CONCLUSION

5.1. Repercussions on the Procedure for Measuring Floor Surface Slip Resistance In Situ

This new elastomer meets the conditions for which it has been developed. In-company measurement procedure is simplified as a result. Conditioning for about 20 hrs of the elastomer in a product likely to be on the floor is no longer necessary. Given the variety of these products (cf. previous section) and the difficulty in procuring or preserving them, this premeasurement stage was the most tedious and limited the systematic use of this appliance for measuring slip resistance in situ.

Figure 3 also highlights a very large difference between the elastomer E1 stabilized measurement (friction index close to 0.35) and the elastomer E4 stabilized measurement (friction index close to 0.60).

Consequently, methods for slip resistance measurements under lubricated conditions must closely specify the precise reference and characteristics of the elastomer for at least two reasons:

- some kinds of elastomer can be impregnated by the lubricant and the measuring procedure must take into account this impregnation;
- the safety threshold associated more or less explicitly with each measuring method must be adjusted if the reference elastomer is changed. Comparisons in floor surface or footwear slip resistance have shown that adjustment between two series of measurements taken according to two different methods is often linear (e.g., Jung & Fisher, 1993). Consequently, the deduction of the relation between two safety thresholds associated with two different methods of measurement is therefore straightforward.

5.2. Conclusion

For around 30 years, slip resistance measurement methodology has been the subject of extensive experimental work (cf. Leclercq [1999], who offers a review of this work). Measuring conditions, such as the pressure at the elastomer/floor interface or the sliding speed, are parameters whose effects on slip resistance measurement have been widely studied in general. On the other hand, the effect of elastomer impregnation by the lubricant, when measurements are taken under lubricated conditions, has only recently been highlighted (Leclercq, Tisserand, & Saulnier, 1993b). There is some confirmation that this effect may be determining in relation to the measurement of slip resistance. Measuring methods can vary in their principle just as in the selection of their parameters (e.g., pressure, sliding speed, reference elastomer) and they are not all equally sensitive to variations in these different parameters. In the case of measurements under lubricated conditions taken with the previously described Portable Friction Tester (PFT), redefinition of a reference elastomer has proved necessary. It is possible that this precaution may also be required in other measurement configurations.

REFERENCES

Gronqvist, R. (1995). Mechanisms of friction and assessment of slip resistance of new and used footwear soles on contaminated floors. *Ergonomics*, *38*(2), 224–241.

Jung, K., & Fisher, A. (1993). An ISO test method for determining slip resistance of footwear. Determination of its precision. *Safety Science*, *16*, 115–127.

Laboratoire de Recherche et de Contrôle des Caoutchoucs et des Plastiques (LRCCP). (1997). Composition de caoutchouc pour la mesure de la glissance des sols au moyen de l'appareil portable PFT. Rapport d'essais [Elastomer compound to measure floor slip resistance with the portable device PFT. Test report] (Report No. 765). Vitry sur Seine, France: Author.

Leclercq, S. (1999). The prevention of slipping accidents: A review and discussion of work related to the methodology of measuring slip resistance. *Safety Science*, *31*, 95–125.

Leclercq, S., Tisserand, M., & Saulnier, H. (1993a). Assessment of the slipping resistance of floors. In R. Nielsen and K. Jorgensen (Eds.), *Advances in industrial ergonomics and safety V* (pp. 521–527). London, UK: Taylor & Francis.

Leclercq, S., Tisserand, M., & Saulnier, H. (1993b). Quantification of the slip resistance of floor surfaces at industrial sites. Part I. Implementation of a portable device. *Safety Science*, *17*, 29–39.

Leclercq, S., Tisserand, M., & Saulnier, H. (1993c). Quantification of the slip resistance of floor surfaces at industrial sites. Part II. Choice of optimal measurement conditions. *Safety Science*, *17*, 41–55.

Leclercq, S., Tisserand, M., & Saulnier, H. (1994). Assessment of the slip-resistance of floors in the laboratory and in the field: Two complementary methods for two applications. *International Journal of Industrial Ergonomics*, *13*, 297–305.

Leclercq, S., Tisserand, M., & Saulnier, H. (1995). Tribological concepts involved in slipping accident analysis. *Ergonomics*, *38*(2), 197–208.

Moore, D.F. (1972). *Friction and lubrication of elastomers*. Oxford, UK: Pergamon.

Strandberg, L. (1985). The effect of conditions underfoot on falling and overexertion accidents. *Ergonomics*, *28*(1), 131–147.

Strandberg, L., & Lanshammar, H. (1981). The dynamics of slipping accidents. *Journal of Occupational Accidents*, *3*, 153–162.

Tisserand, M. (1985). Progress in the prevention of falls caused by slipping. *Ergonomics*, *28*(7), 1027–1042.