Health & Safety International

The Journal for Employee Protection

Issue 33 | April 2010

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A practical comparison between outdoor footwear and safety footwear

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Sensit Technologies ist ein Familienunternehmen, das modernste Gasdetektionsprodukte zum Schutz von Menschen herstellt; mit denen Gaslecks schnell und einfach erkannt und exakte Messungen toxischer Gase geliefert werden.

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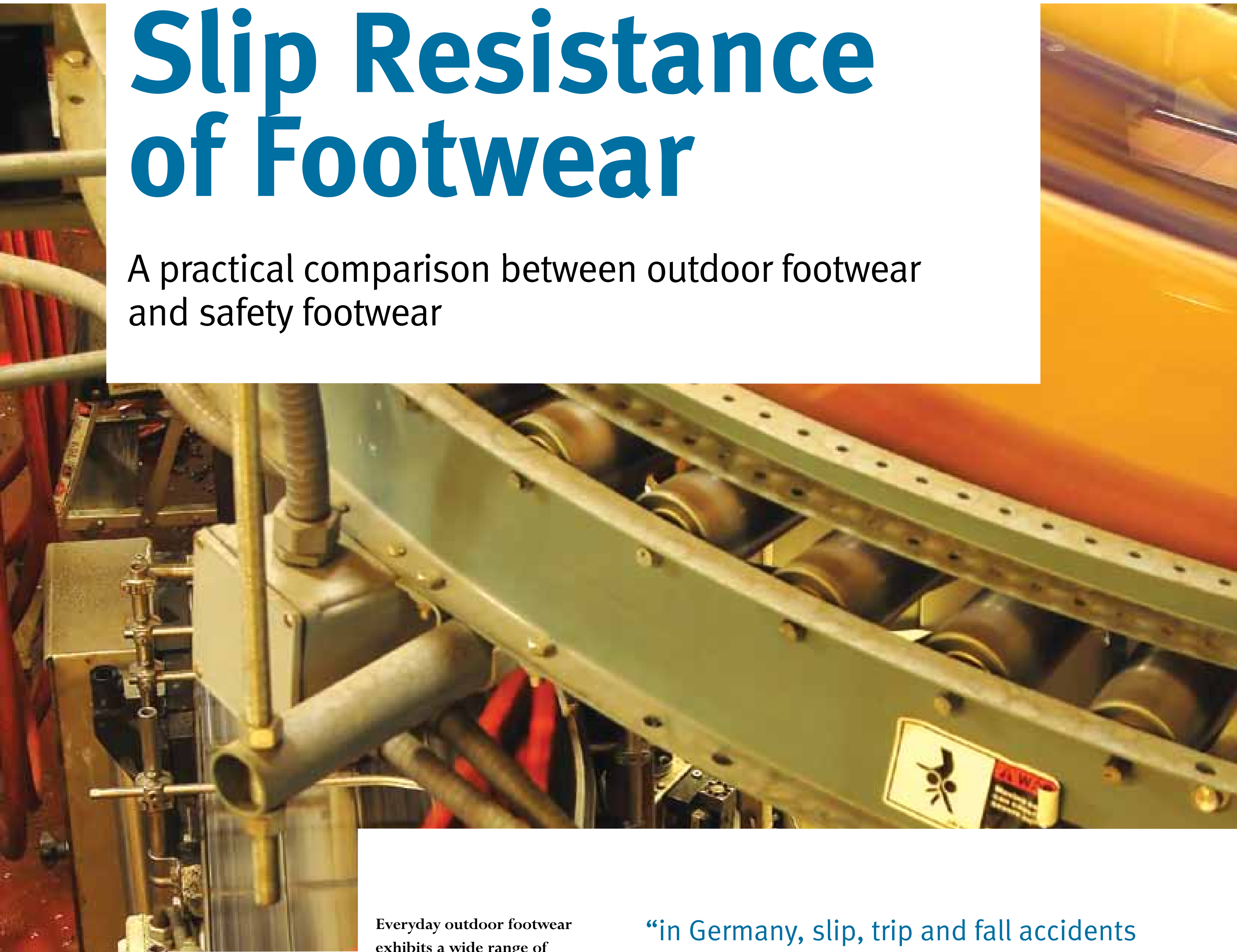
Bei den vielen verschiedenen Lichtquellen, die wir heutzutage haben, neigen wir dazu zu vergessen, dass in Kohlebergwerken seit vielen Jahren mit offenen Flammen gearbeitet wird. Ron Sinclair

Slip Resistance of Footwear

A practical comparison between outdoor footwear and safety footwear



Everyday outdoor footwear exhibits a wide range of potential slip resistance. The roughness, tread and hardness are components with only a minor influence upon the slip resistance. The material combination is probably the decisive factor determining the slip resistance.

> "in Germany, slip, trip and fall accidents account for 20% of industrial accidents and 25% of accidents in the private sphere"

Accidents caused by slipping occur in all work areas. Only in some of these areas however is safety, protective or occupational (SPO) footwear worn. In publicly accessible and administration areas, on pedestrian surfaces and in numerous production areas, the wearing of safety footwear is not mandatory. Employers generally have no influence upon the outdoor footwear worn by their employees. In Germany, slip, trip and fall accidents account for 20% of industrial accidents and 25% of accidents in the private sphere. Since these accidents occur on a range of floor coverings with both outdoor footwear and SPO footwear, the department of safety engineering/ occupational safety at the University of Wuppertal studied the slip resistance of worn outdoor footwear on a number of floor coverings, and compared it to that of SPO footwear.

The slip resistance of SPO footwear is tested by means of shoe-testing machines to EN ISO 13287[1] by measurement of the coefficient of dynamic friction (the ratio of the horizontal force to the vertical force) (Fig.1). Minimum requirements for the placing of such shoes on the market are set out in standards (see EN ISO 20344 to 20347[2]). Every year, some 14 billion[3] pairs of shoes are produced worldwide. In contrast to SPO footwear, outdoor footwear is not subject to any statutory or normative requirements governing the testing of its slip resistance and its placing on the market. In addition, very little is available in the way of research results ▸

concerning the slip resistance of worn outdoor footwear.

Methods and test material

The slip resistance of the soles of worn outdoor and leisure footwear was studied during a BA thesis completed at the University of Wuppertal (Schotes, 2009[4]). The study focussed upon the influence of the sole properties, the surface roughness, the tread (contact surface) and the hardness upon the slip resistance. The slip resistance of the outdoor footwear was then compared with the provisions of standards governing SPO°footwear. In the next phase of the study, the slip resistance was measured and assessed in a selection of realistic situations involving various floor coverings.

Altogether, 29 worn women's shoes (L shoe) and 32 worn men's shoes (M shoe) belonging to 7 persons, 3 safety shoes (SPO°shoe) and 2 shoes with reference sole material (Ref shoe) were examined. The soles of the reference shoes are manufactured from SBR and Slider 96, which are employed in accordance with DIN 51131[5] and EN 13845[6] as reference materials for the testing of floor coverings. The slip resistance was measured by means of a test machine in accordance with the EN ISO 13287 test standard, which has been applicable internationally since 2008. The studies were limited to the test combination ceramic tile with water + 0.5% sodium dodecyl sulphate as the lubricant in the 0° shoe position.

The influencing factors of roughness and hardness were measured in accordance with the relevant standards. The contact surface was determined by means of an imprint, and corresponds to the area in contact with the test floor covering during the test on the machine.

Results

Slip resistance and other material properties of outdoor footwear

Fig. 2 shows the results of measurements on the shoes studied. Coefficients of dynamic friction μ were measured in the range from 0.10 to 0.51.

For the 29 women's shoes studied, the roughness values Rz (measured in accordance with EN ISO 4288[7], filter 0.8 mm) lie between 8 μm and 43 μm, those for the 32 men's shoes between 11 μm and 58 μm.

Measurements (to EN ISO 868[8]) of the hardness of the shoe soles yielded values ranging from 42 Shore A to 97 Shore A. The contact surfaces of the load-bearing sole treads under load lie between 14% and 41% of the entire sole area.

The relationship between the parameters of sole roughness, sole hardness and contact surface area on the one hand and slip resistance to EN ISO 13287 on the other was examined by way of a correlation analysis.

The results of the correlation analysis (Fig. 3) show that in the examined random sample of shoe soles, neither the sole roughness ($r = 0.057$) nor the sole hardness ($r = 0.036$) or contact surface area ($r = 0.227$) has a significant impact upon the coefficient of friction μ.

Comparison of outdoor footwear with safety footwear

SPO footwear may be placed on the market only if the soles are of slip-resistant design. The observance ▸

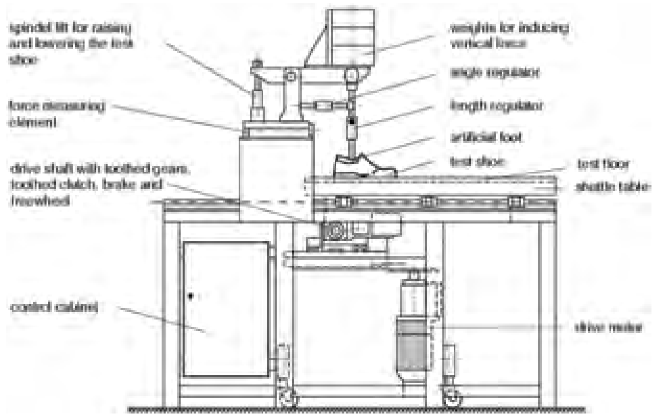


Fig. 1: Example of a shoe-tester to EN ISO 13287

"for working areas where safety footwear is not mandatory, approximately half of the footwear worn could contribute to slip under realistic conditions"

shoe identification	size	CoF	Rz [µm]	hard-ness shore A	contact area %	shoe identification	size	CoF	Rz [µm]	hard-ness shore A	contact area %
L-Shoe 1	40	0.37	8	43		M-Shoe 1	43	0.19	17	46	33
L-Shoe 2	40	0.22	26	42		M-Shoe 2	43	0.15	19	70	25
L-Shoe 3	40	0.37	12	60		M-Shoe 3	43	0.18	23	63	14
L-Shoe 4	39	0.21	17	54	14	M-Shoe 4	43	0.28	26	56	
L-Shoe 5	39	0.31	40	53		M-Shoe 5	43	0.38	13	67	
L-Shoe 6	40	0.10	14	56		M-Shoe 6	44	0.24	34	64	
L-Shoe 7	43	0.41	11	60	34	M-Shoe 7	42	0.43	11	74	39
L-Shoe 8	39	0.26	33	50	17	M-Shoe 8	45	0.24	13	58	
L-Shoe 9	40	0.29	12	57		M-Shoe 9	43	0.27	23	52	
L-Shoe 10	40	0.38	24	55		M-Shoe 10	39	0.34	24	45	
L-Shoe 11	40	0.26	21	53		M-Shoe 11	40	0.21	15	74	
L-Shoe 12	40	0.14	43	58	30	M-Shoe 12	44	0.13	35	49	17
L-Shoe 13	41	0.21	26	74		M-Shoe 13	44	0.35	23	55	
L-Shoe 14	40	0.34	35	52		M-Shoe 14	44	0.24	25	68	
L-Shoe 15	41	0.47	40	62	35	M-Shoe 15	44	0.29	21	48	
L-Shoe 16	40	0.26	29	62		M-Shoe 16	44	0.18	15	65	
L-Shoe 17	40	0.28	16	60		M-Shoe 17	47	0.21	14	64	
L-Shoe 18	40	0.29	21	61		M-Shoe 18	47	0.36	22	65	
L-Shoe 19	42	0.26	19	95		M-Shoe 19	47	0.17	33	67	
L-Shoe 20	41	0.13	27	61		M-Shoe 20	47	0.26	22	67	
L-Shoe 21	42	0.37	18	69		M-Shoe 21	47	0.35	20	62	
L-Shoe 22	42	0.32	30	86		M-Shoe 22	43	0.37	17	75	
L-Shoe 23	42	0.31	26	83		M-Shoe 23	42	0.44	16	62	
L-Shoe 24	38	0.20	18	73		M-Shoe 24	43	0.42	23	63	
L-Shoe 25	39	0.31	23	88		M-Shoe 25	44	0.34	17	52	
L-Shoe 26	39	0.33	12	97		M-Shoe 26	43	0.39	30	77	
L-Shoe 27	40	0.27	14	82		M-Shoe 27	43	0.49	35	60	23
L-Shoe 28	41	0.14	33	59		M-Shoe 28	43	0.51	58	48	41
L-Shoe 29	41	0.32	24	57		M-Shoe 29	44	0.37	22	67	
SPO-Shoe 1	42	0.53	10	75	22	M-Shoe 30	44	0.19	23	58	
SPO-Shoe 2	42	0.50	13	50	20	M-Shoe 31	44	0.33	15	51	
SPO-Shoe 3	42	0.39	10	75	25	M-Shoe 32	45	0.34	26	55	
Ref-Shoe SBR	42	0.29	14	97	48	Ref-Shoe S96	43	0.28	6	92	48

Fig. 2: Overview of the tested shoes and their measured properties

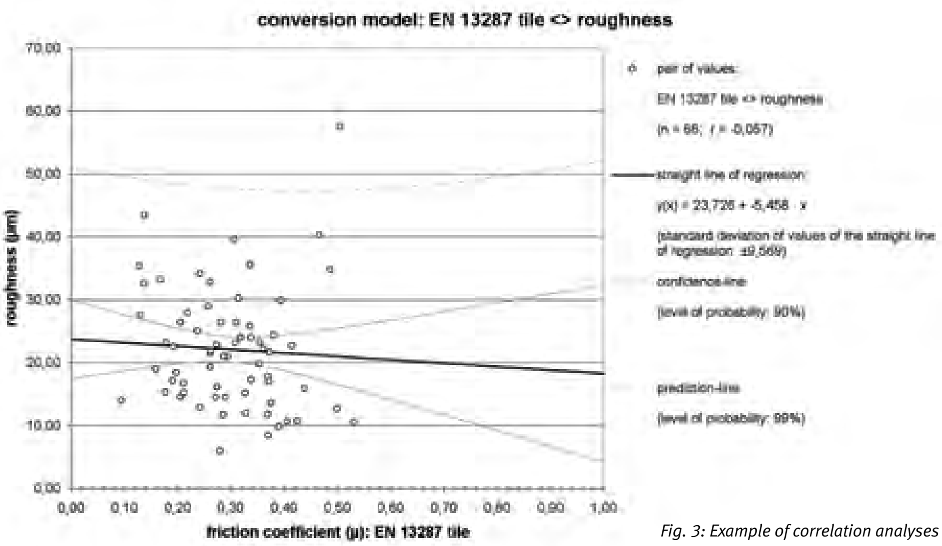


Fig. 3: Example of correlation analyses

Fig. 4: Protection concept: "Action value and limit value of the coefficient of friction while walking"; Sebald, J. 2009

of this protection requirement, which is stated in the EU PPE Directive[9], can be attained and demonstrated by application of the harmonized standards EN ISO 20344 to 20347. In order for an item of footwear to be designated SRA or SRC, it must attain a coefficient of friction of at least 0.32 in the relevant test, "Level forward slipping on the ceramic tile with SDS water". The study (Sebald, 2009[10]) of 52 items of safety, protective and occupational footwear upon which the comparison was based yields coefficients of friction of between 0.31 and 0.57.

Of the outdoor footwear studied, a total of 37 of 61 tested shoes have a coefficient of friction below 0.32. Were the normative provisions governing safety footwear to be applied to outdoor footwear, 61% of the tested shoes would fail to satisfy them. At 0.10-0.51, the range of the potential slip-resistance properties of outdoor footwear is substantially wider than that of safety footwear. The results show that good outdoor footwear is on a par with good safety footwear; for example, a men's sandal with almost no tread attained similar values in the study to very good safety shoes.

For the large number of working areas in which the wearing of safety footwear is not mandatory, it may be assumed that approximately half of persons wear footwear which could contribute to slipping under realistic conditions, particularly on wet surfaces.

Practical test involving further floor coverings

Supplementary to the footwear tests to EN ISO 13287, the slip resistance of selected shoes was tested under realistic conditions on a selection of nine floor coverings typical of public and industrial areas (materials: plastic, wood, ceramics and concrete stone) and with water as the lubricant.

The footwear selected for these tests involved five safety and reference shoes and twelve outdoor shoes representative of the range of the materials under examination. The nine floor coverings are representative non-textured floor covering products for indoor and outdoor areas with low to medium slip-resistance properties (corresponding to the German R classes R-, R9 and R10 to DIN 51130[11]).

The tests were performed by means of the floor and shoe tester (Fig. 1).

The results were evaluated by means of the "Action value and limit value of the coefficient of friction while walking" protection concept (Sebald 2009, see Fig. 4), which describes the requirements concerning the frictional system comprising the floor covering, the lubricant and the shoe and was derived from the biomechanical requirements placed upon the frictional system. In accordance with the protection concept, it may be assumed that the probability of slipping is high when the coefficient of friction tested under realistic conditions lies below 0.30.

Results of the test under realistic conditions

The results of the test under realistic conditions are shown in Figure 5. The coefficients of friction range from 0.13 to 0.83. Application of the "Action value and limit value of the coefficient of friction while walking" protection concept to the results of the real-case test illustrates that in many situations, the coefficients of dynamic friction of these specific slip-resistance systems fall below the limit value of 0.30 (highlighted in ▶

Floor	ceramic tile (EN ISO 13287)	PVC	concrete block, sealed	laminate 1	laminate 2	concrete block, grinded	stoneware polished	ceramic tile, glazed	concrete block, grinded	ceramic tile
Class of Friction (DIN 51130)	R9	R-	R-	R-	R-	R9	R-	R9	R10	R10
shoe identification	CoF	CoF	CoF	CoF	CoF	CoF	CoF	CoF	CoF	CoF
M-Shoe 12	0.13	0.22	0.43	0.20	0.33	0.36	0.27	0.15	0.44	0.25
L-Shoe 12	0.14	0.23	0.39	0.16	0.24	0.38	0.19	0.15	0.45	0.14
M-Shoe 2	0.16	0.17	0.44	0.16	0.29	0.48	0.24	0.15	0.44	0.18
M-Shoe 3	0.18	0.20	0.45	0.30	0.36	0.49	0.30	0.17	0.57	0.16
M-Shoe 1	0.19	0.20	0.44	0.21	0.33	0.45	0.31	0.16	0.41	0.19
L-Shoe 4	0.21	0.22	0.53	0.20	0.32	0.56	0.29	0.21	0.59	0.24
L-Shoe 7	0.22	0.30	0.29	0.22	0.36	0.53	0.24	0.23	0.57	0.34
L-Shoe 8	0.26	0.30	0.50	0.20	0.32	0.70	0.28	0.26	0.46	0.25
Ref-Shoe (S96)	0.28	0.56	0.23	0.48	0.53	0.37	0.18	0.21	0.36	0.33
Ref-Shoe (SBR)	0.29	0.24	0.33	0.20	0.30	0.58	0.23	0.19	0.55	0.41
SPO-Shoe 3	0.39	0.47	0.42	0.32	0.50	0.64	0.28	0.33	0.55	0.43
M-Shoe 7	0.43	0.24	0.42	0.28	0.38	0.72	0.22	0.27	0.75	0.38
L-Shoe 15	0.47	0.29	0.43	0.46	0.49	0.61	0.33	0.43	0.49	0.47
M-Shoe 27	0.49	0.31	0.38	0.38	0.45	0.57	0.29	0.40	0.54	0.50
SPO-Shoe 2	0.50	0.33	0.46	0.31	0.50	0.83	0.35	0.45	0.66	0.57
M-Shoe 28	0.51	0.34	0.45	0.43	0.47	0.67	0.35	0.42	0.53	0.54
SPO-Shoe 1	0.53	0.28	0.35	0.30	0.47	0.77	0.24	0.39	0.63	0.56
average	**0.32**	**0.29**	**0.41**	**0.28**	**0.39**	**0.57**	**0.27**	**0.27**	**0.53**	**0.35**

Fig. 5: Coefficients of dynamic friction of selected shoes on realistic floor coverings

red). In such cases, an elevated risk of slipping exists. Situations are also described which lie within the safe range, i.e. above the action value of 0.45 (highlighted in green). "Polished fine stoneware" proved to be a particularly problematic floor covering material. Only four scenarios lie above the limit value of 0.30. No item of footwear can be selected in combination with this floor covering for which the coefficient of dynamic friction exceeds the action value of 0.45.

In order to enable the items of footwear to be compared, the coefficients of friction μ of the soles of the selected shoes as shown in Fig. 5 are divided into four percentile ranges for each floor covering ("low" = lower 10th percentile; "below average" = from the lower 10th percentile to the average value; "above average" = from the average value to the upper 10th percentile; "high" = upper 10th percentile).

The frequency distribution within the ranges (Fig. 6) shows clearly that the majority of shoes can be assigned to the upper range (e.g. SPO shoe 2, M shoe 28, L shoe 15), the one of the middle ranges or the lower range (e.g. M shoe 12, L shoe 12) of slip resistance with all floor coverings. Essentially, this classification of the footwear also correlates closely to the classification of the shoes by the results in accordance with EN ISO 13287. The shoe with the "Slider 96" sole is a special case.

Special case: Slider 96 sole

The shoe with the Slider 96 sole material (Ref shoe S96) differs in particular in its properties from the other shoes studied. On the one hand, the Slider 96 sole delivers low values in the "below average" and "low" ranges on concrete and ceramic floor coverings. On the other, the coefficients of friction of the Slider 96 sole are in the "high" range on PVC and laminate floor coverings. The Slider 96 sole attains very low or very high values compared to the other items of footwear, depending upon the floor covering material. This shows clearly that the floor covering and sole materials have an influence in combination upon the slip-resistance properties.

The Slider 96 sole material is employed in Europe in several standards for testing of the slip resistance of floor coverings. These standards include EN 13845, EN 13036-4[12] and BS 7976-2[13]. Consideration must be given to the fact that measurements involving the Slider 96 sole yield results which differ from those obtained with other typical sole materials. As a result, it is questionable whether the Slider 96 sole material is suitable for use as reference shoes for the floor covering test and thus whether floor coverings can be assessed correctly in practical situations.

For validation of the measurement results from this study, selected test results involving the Slider 96 shoes and other shoes were tested on the ramp with reference to EN 13845. Results comparable to those from the machine test method were obtained.

Conclusion and prospects

The studies may be summarized as follows:

- *For all researched shoe materials, the present studies found no correlation between the slip resistance and the parameters of roughness, hardness or contact surface area. Based upon the current state of knowledge, it is assumed that the sole material is the decisive factor influencing the slip resistance when water is employed as the lubricant*

- *The potential slip resistance of outdoor footwear exhibits a substantially higher range than does that of safety shoes. Good outdoor footwear is on a par with good safety footwear. Over 50% of outdoor footwear would fail to satisfy*

> "it is assumed that the sole material is the decisive factor influencing the slip resistance when water is employed as the lubricant"

	Frequency of high/middle/low slip resitance			
shoe identification	high	above average	below average	low
M-Shoe 12	0	2	5	3
L-Shoe 12	0	0	3	7
M-Shoe 2	0	1	4	5
M-Shoe 3	0	4	3	3
M-Shoe 1	0	2	5	3
L-Shoe 4	1	2	7	0
L-Shoe 7	0	3	7	0
L-Shoe 8	0	4	6	0
Ref-Shoe (S96)	3	0	3	4
Ref-Shoe (SBR)	0	3	7	0
SPO-Shoe 3	0	10	0	0
M-Shoe 7	1	5	4	0
L-Shoe 15	3	6	1	0
M-Shoe 27	0	9	1	0
SPO-Shoe 2	5	5	0	0
M-Shoe 28	3	7	0	0
SPO-Shoe 1	1	6	3	0

Fig. 6: Overview of incidence in the value ranges

> “voluntary testing and marking of outdoor footwear by manufacturers with reference to such standards would be desirable”

the provisions of the standards governing safety footwear

- *The technical suitability of Slider 96 for use as a reference sole for the testing of floor coverings is called into question*

The results of the study show the shoe sole to be an essential influencing factor in the slip-resistance system comprising shoe, floor covering, lubricant and pedestrian, especially when the lubricant is waterbased. In order for the risk of slipping to be reduced, further studies are required. In particular, the slip resistance of outdoor footwear should be studied further, since critical situations which may lead to slipping arise both in working areas and in leisure areas. Improvement necessitates, among other things, selection of a suitable test method, a suitable assessment of relevance to real-case conditions, and the laying down of standards for outdoor footwear. Voluntary testing and marking of outdoor footwear by manufacturers with reference to such standards would be desirable.

In order for more comprehensible conclusions and findings to be obtained with regard to combinations of floor coverings and (safety and outdoor) shoe materials, a slip-resistance matrix is being developed in a research project at Wuppertal University. In the project, which is to run until 2012, the combinations of 70 floor coverings with 100 shoes are being studied in consideration of water and oil as lubricants. The objective is for the research results to deliver comprehensive information for practical situations, by means of which floor coverings and footwear can be classified in a manner relevant to practical application for the lubricants of water and oil. With its special selection of material for examination which is typical of real-case applications, the objective is that of enabling firm conclusions to be reached regarding the slip resistance of various material combinations.

The project is being conducted on behalf of and with sponsorship from the German Social Accident Insurance (http://www.dguv.de). ■

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