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Technical Report: Using Variable Angle Tribometers (VAT) for Measurement of the Slip Resistance of Walkway Surfaces

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ANSI Technical Report

**Using Variable Angle Tribometers (VAT) for
Measurement of the Slip Resistance of Walkway Surfaces**

Prepared by the American Society of Safety Engineers

Registered November 16, 2007

by the American National Standards Institute, Inc.

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FOREWORD

Subcommittee A1264.2 of the A1264 Accredited Standards Committee *Safety Standards for Floor and Wall Openings, Railings, and Toeboards and Fixed General Industrial Stairs* of the American National Standards Institute developed this technical report to provide guidance for the performance of slip resistance testing of walkway surfaces in situ. The A1264.2 Subcommittee operates under the auspices of the ANSI A1264 ASC and its accredited Standards Development Organization – The American Society of Safety Engineers (ASSE).

This technical report is intended as a companion document to ANSI A1264.2 *Provision of Slip Resistance on Walking/Working Surfaces*. The intent of A1264.2 is to help reduce falls due to preventable conditions by providing guidelines and recommendations for the minimum performance requirements for increased safety on walking/working surfaces. The intent of this technical report is to provide a scientific basis and guidance for certain devices in evaluating walking/working surface slip resistance properties and/or frictional characteristics.

There have been and continue to be a number of standards activities related to the measurement of slip resistance on walkway surfaces. These initiatives tend to be long-term projects that take many years to develop. Therefore, a technical report assembling the scientific, legal, and standards development literature provides timely and much needed guidance.

This technical report complements the objectives of the A1264.2 standard, providing support for the use of slip resistance test instruments.

The standards committee offers this technical report as the state of the art, understanding that development in this area continues, and revisions to this report may be necessary as tribometric science progresses.

There are two appendices at the end of the technical report that provide operating protocols for the two slip resistance testers discussed in this report – the Brungraber Mark II/III Slip Tester and the English XL Tribometer.

Publication of this Registered Technical Report has been approved by the A1264 ASC and registered with ANSI by the American Society of Safety Engineers. This document is registered as a Technical Report series of publications according to the procedures for the Registration of Technical Reports with ANSI. This document is not an American National Standard and the material contained herein is not normative in nature. Comments on the content of this document should be sent to: The Director of Practices and Standards, American Society of Safety Engineers, 1800 East Oakton Street, Des Plaines, IL 60018.

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ANSI TECHNICAL REPORT TR-A1264.3 USING VARIABLE ANGLE TRIBOMETERS (VAT) FOR MEASUREMENT OF THE SLIP RESISTANCE OF WALKWAY SURFACES

OVERVIEW

Purpose and Scope

This technical report discusses the technical aspects, research, legislation, standards activities, and operation of the widely-used Variable Angle Tribometers (VATs) commercially available for testing of walkway surface slip resistance: The Brungraber Mark II/III and the English XL.

TERMINOLOGY

- *Adhesion*: The tendency of two surfaces in forceful contact to stick together. The resulting increased resistance to slipping may become greater as residence time increases.
- *Sticktion*: A phenomenon in which a liquid film is squeezed out of the interface between the shoe bottom and the walkway surface as a result of residence time. Sticktion can result in slip meter readings that are unexpectedly high under wet conditions.
- *Dwell time (residence time)*: The period of time between initial footwear or test pad contact with the walkway or test surface and the instant that relative motion is initiated. Residence time produces adhesion and sticktion. Slip meters which apply the vertical and horizontal force components simultaneously avoid sticktion on wet or contaminated surfaces and adhesion on dry surfaces.

Apparatus Description and Operating Principles

The phenomena of “adhesion” (involving dry surfaces) and “sticktion” (involving wet surfaces) are associated with slipmeters designed to remain stationary on a surface for some period of time before operating (known as “residence time” or “dwell time”). Dwell times as short as 0.2 seconds are known to be capable of producing this phenomenon. Adhesion and sticktion can result in higher readings than would be obtained on the same surface if testing occurs when the test foot and the walkway surfaces make contact with no dwell time. This difference is especially evident under wet conditions. Devices that avoid sticktion by applying the horizontal and vertical force components simultaneously (thereby avoiding dwell time) are suitable for testing under wet as well as dry conditions.

Variable-angle tribometers use a test foot in motion when it contacts the surface being tested, similar to non-scuffing human ambulation. The ratio of horizontal to vertical force is adjusted by the operator by changing the angle of incidence of the strut holding the test foot until a slip occurs.

The Brungraber Mark II/III and the English XL have been the subject of numerous peer-reviewed publications, collaborative studies, consensus standards development, regulatory adoption, and case law. They are used by many experts as suitable portable devices for measuring slip resistance properties of wet and dry surfaces.

The Brungraber Mark II/III

In the 1980's, subsequent to the development of the Mark I tribometer, Dr. Brungraber invented the Mark II. A gravity-based articulated strut instrument designed to avoid the “sticktion” problem, the Mark II/III enables users to meter wet surfaces. It does so by eliminating the dwell time between the application of the vertical and horizontal forces. More recently, a spring actuated Mark III version has been developed. This reduces the weight of the tester and makes it independent of gravity so that inclined, even vertical, surfaces can be tested.

The Mark II/III is a portable apparatus fitted with a 3 inch by 3 inch test foot, which can be of any shoe sole or heel material, or of Neolite® Test Liner, grooved if desired. It uses a ten-pound weight on an inclinable frame, with a test pad of Neolite® Test Liner suspended just above the walkway surface. Each time the angle is set to a more horizontal position the weight is released, until a slip occurs. The slip resistance reading can be taken directly from the instrument.

Misleadingly low slip resistance readings obtained in wet tests are avoided through the use of a grooved test foot. If the test foot is not grooved, the flat orientation of the test foot as it strikes the surface creates a “hydroplaning” effect. Independent studies by several researchers (Fleisher-Medoff-Di Pilla, Grieser-Rhoades-Shah, Flynn-Underwood) clearly demonstrate low results due to hydroplaning can be overcome by using a grooved test foot on the Brungraber Mark II/III, to permit a path for the displaced water. Using a grooved test foot on the Brungraber Mark II/III also provides results similar to those obtained by the English XL equipped with a smooth test foot.

The Mark II/III is under patent by Dr. Brungrabers’ company, Slip Test Inc. (1900 Fourth Avenue, Spring Lake, NJ 07762), which is also the only manufacturer. There are several applicable patents: 4,759,209 (issued July 26, 1988); 4,798,080 (issued January 17, 1989); and 5,576,478 (issued November 11, 1996).

English XL

In the early 1990’s, William English developed the English XL, an articulated strut device similar in principle to the Mark II/III. However, the English XL relies not on gravity, but is powered by a small carbon dioxide cartridge at a set pressure.

The instrument has an aluminum frame onto which is attached a hinged aluminum mast. The angle of the mast can be adjusted by a hand wheel from vertical 90 degrees to approximately 45 degrees. The mast holds a pneumatic piston, which drives a rod towards the surface being tested. The end of the rod holds a 1.25” round test foot on a spring-and-joint assembly, which makes contact with the surface. The pneumatic piston is powered by carbon dioxide at a constant pressure. The angle of the mast is adjusted from a relatively more vertical position to a relatively more horizontal position until a slip occurs.

The slip index can be read directly from the protractor mounted on the instrument. While the standard recommends the use of Neolite® Test Liner for floor testing (see below), any material can be mounted on the test foot.

The instrument has several features that make it suitable for field-testing:

- The test foot cylinder contacts the walkway surface in a heel-first attitude of contact.
- The velocity of contact is consistent with strobe flash experiments of heel contact speed (Perkins, 1978).
- While some researchers have suggested the small dimensions of the test foot makes the instrument inappropriate for testing of highly textured or profiled surfaces, the size of the test foot is similar to the initial area of heel contact in human walking.
- The compressed gas delivers a uniform force, and permits metering of inclined surfaces such as ramps unhampered by the impact of gravity activation.
- Like the Brungraber Mark II/III, the application of vertical and horizontal forces is simultaneous, thus avoiding residence-time and permitting reliable wet test results.

The English XL is currently still under patent (5,259,236, issued November 3, 1993). The only manufacturer is William English Inc. (20500 N. River Rd., Alva, FL 33920). It is available through <http://www.englishxl.com>.

Test Foot Material

Test foot material is the surface that makes contact with the floor surface when making slip resistance measurements. Appropriate test foot material is essential to accurate, reliable, and valid baseline readings.

In the early 1990's, ASTM Technical Committee F13.10 began a study to identify a more suitable material than leather for walkway surface slip resistance testing. It was found that the best available material was a test grade of Neolite[®], originally developed, patented, and trademarked by the Goodyear Tire & Rubber Company. It was specified by several ASTM test methods.

This type of Neolite[®] was at one time used by the footwear industry as a heel material. Documents from the U.S. Trademark Electronic Search System (TESS) verify that Goodyear registered this material in 1953 as “soles and heels composed of an elastomer and a resin.”

Neolite[®] is the original styrene-butadiene rubber (SBR), of which many varieties are routinely used as footwear bottom material. Under the trade name Neolite[®], it was sold in sheet form and die-cut to sole shapes for adhesive attachment. Its special properties were that it had flexibility and adequate wear resistance, and felt and behaved underfoot much like leather, rather than rubber. Soling of this kind has now become widely known and used, and is often referred to as, resin-rubber.

To date, a more suitable material than Neolite[®] has not been identified for floor friction testing:

- It is a generic and durable substance. The characteristics of the material do not change under normal conditions, regardless of wear or moisture;
- The special test grade (or scientific grade) of Neolite[®] Test Liner used is manufactured with specific quality controls regarding hardness and consistency of physical properties. It is also made to a specific recipe and tested for consistency of physical properties according to a former Rubber Manufacturers' Association (RMA) specification HS-3 for use as a friction pad material, specifying Shore Hardness of 93-96, specific gravity 1.25 +/- 0.02, 1/8" thickness;
- It is stable over time;
- Its traction properties are in the median range of commonly used shoe bottom materials;
- It has been proven reliable and repeatable over many years in service as a friction pad material, as the material of choice for the Horizontal Pull Dynamometer Pullmeter (ASTM C1028), the Horizontal Pull Slipmeter, the Brungraber Mark II/III, and the English XL (Flynn, Underwood). It was the material of choice by the National Bureau of Standards (now National Institute of Standards and Technology) in its studies on the use of tribometers on wet surfaces.

The thickness of Neolite[®] can vary (1/8" or 1/4"). Studies indicate that the results of the English XL are not dependent on the thickness of the test foot, primarily because it is a constant-velocity device, being driven by gas pressure.

Currently, Neolite[®] Test Liner is manufactured and supplied primarily through Smithers Scientific Services, Inc., 425 W. Market Street, Akron, Ohio, although most any manufacturer of footwear bottom material can produce it. The consensus of many slip resistance experts is that Neolite[®] Test Liner is the best currently available material for testing floor surfaces to establish slip resistance.

Extent of Use of VATs

- Types of Uses

Product Design. When designing walkway materials and related products, cleaners, and treatments, slip testing can be an invaluable tool in comparing formulations, patterns, textures, and other design features with each other to achieve a suitable balance between function and aesthetics.

Quality Control. Slipmeters can be used to perform quality control on floor conditions, assessing the effectiveness and life of flooring materials in use, and the effectiveness of cleaning, housekeeping, and maintenance regimens.

Audits/Problem Identification – Prevention. In order to take corrective action, you must first know where the problems are. In combination with a preliminary analysis of losses, slip resistance testing can assist in identifying problem conditions before they produce accidents. Areas that should be considered include those with high traffic, entrance/exit areas, and areas where history indicates problems may exist.

There are times in which loss history cannot be analyzed because this information is unknown or unavailable. Examples include new ventures, the use of new flooring materials, poor prior accident reporting and investigation procedures, and the acquisition of new properties or business units. In such instances, slip resistance testing alone can be instrumental in helping to identify areas of potential concern.

Claims Defense/Documentation. Performing and documenting periodic slip testing on surfaces that may be subject to slip and fall claims as part of an ongoing prevention program can be effective in minimizing claim occurrences and costs.

Accident Investigation. Any factual investigation done today can be scrutinized through the legal process of discovery at a later point in time. Because of this, it is essential that all factual investigation support for claims, including slip resistance testing, be thorough and accurate. Prompt testing of the area in question and clear and concise documentation of the results can be critical in determining whether or not the floor surface contributed to the accident.

Material Specifications/Assessment of Floor Treatment/Cleaning Products and Methods. Slip resistance testing can provide a means of directly comparing the relative effectiveness of current or proposed floor treatments, cleaning products, and cleaning methods upon application and over time. The systematic approach to selecting an effective floor treatment, or to evaluate a cleaning regimen is a controlled evaluation. Finding the right product is more a process of elimination. Working with a professional will enable you to document the steps that support your flooring recommendation.

- Industries

A wide range of industries employ the use of slipmeters, and in particular the English XL and/or the Brungraber Mark II/III. Below is a partial list:

Insurance, Brokers and Service Companies

Federal Government

- GSA
- OSHA
- NASA,
- NIOSH
- US Air Force
- US Navy

Colleges and Universities

Municipal Government

Industrial/Service Companies

- Manufacturers, including conglomerates
- Retailers, including Supermarkets and Convenience Stores
- Entertainment, Cruise Companies, Cultural Institutions
- Healthcare
- Janitorial and Maintenance Companies
- Chemical and Petroleum Product Companies
- Lodging
- Food Service/Restaurants
- Pharmaceutical Companies
- Telecommunications

Consultants, Consulting Companies, and Testing Labs

Floor Treatment Contractors

DISCUSSION

Research Studies

In a thorough study by Powers, Kulig, Flynn, and Brault in 1999, the Brungraber Mark II and English XL demonstrated remarkably low bias, and good repeatability. Work by Chang and Leamon (1997) reported that the Brungraber Mark II and the English XL are both capable of distinguishing surface roughness on wet quarry tile.

Several ASTM workshops have generated much data demonstrating the reliability and consistency of the English XL. Two studies done for the revision of the OSHA Steel Erection Standard bear out the correlation of the instruments' output to the human perception of walking by comparing how English XL and walkers independently rank sets of materials of various degrees of slip resistance (<http://www.cdc.gov/niosh/elcosh/docs/d0100/d000037/d000037.html>).

Ruggedness Testing (June 2002)

This study was undertaken to help determine how instrument factors (operational details, instrument adjustments) and environmental conditions might influence slip resistance results obtained with the English XL. Additionally, once the studies were done, it was hoped that results would lead to suggestions for clarifying the operation of the English XL to improve precision.

The emphasis of this work was to investigate factors that might influence results when a Neolite® test foot is used, since the manufacturer specifies this material for general measurements of walkway slip resistance. Preliminary univariate studies were made, varying one factor at a time to assess their influence on results. Then, more detailed and difficult studies were performed to determine the influence of important factors while simultaneously exploring several different temperatures and humidities. This latter study was performed using a multivariate technique, so a more quantitative indication of the influence of each factor on slip resistance readings could be ascertained.

As with all studies of this kind, the influence of instrument factors and environment depend upon the specific surface/test foot combination being used. So, it is appropriate to have some information to indicate if instrument factors for Neolite® are substantially different from those of other materials. For this reason, preliminary univariate studies were performed on two other test feet: Leather and patterned thermoplastic urethane.

Results for Neolite®

Experimental

Surfaces studied: red quarry tile¹, glazed ceramic tile similar to the C1028 tile², vinyl composition tile (VCT)³, dry and wet with distilled water.

Test foot: Neolite® test liner, as recommended by the manufacturer.

Preliminary Studies. Preliminary studies were performed to determine the factors or settings that were likely to make a difference in results. A Newman-Keuls multiple comparisons test was used to determine significant differences within each set, at the 95% confidence level. The only differences observed were measuring down slope on wet ceramic and measuring at 22 psi on wet VCT.

¹ Metropolitan Ceramics, quarry, Mayflower red 6x6 inch tile, #ESQ-310

² The ASTM C1028 tile (Mexican Sand, 9x9 inch), formerly manufactured by Florida Tile, is no longer being made. Some of the tiles in this study were made by Toprak for Florida Tile and closely resemble the original. These are also no longer being made.

³ Armstrong #56830, Chalk, 12x12 inch tiles, Group II.