MECHANICAL ENGINEERING | RESEARCH ARTICLE

Slip conditions of floor surface finish in selected public places in Kumasi, Ghana

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Abstract: Data from the Accident Centre of the Korle-Bu Teaching Hospital, Accra, Ghana, indicate that between January 2016 and December 2017, there were 19.7% injuries due to falls with 13.7% resulting in deaths. These injuries and deaths may be due to floor surface finishes that have the tendency to cause slip fall and also exacerbated by the floor condition and footwear in contact. In this exploratory studies, tests are conducted on six selected floor surfaces and five footwear soles under dry, wet and dust or oil contaminated conditions for their slip potentials. The tests were performed with pendulum test apparatus. The footwear sole material surfaces that show better performance are leather, commando and rubber. They have Pendulum Test Value (PTV) of about 30, indicating moderate risk in slip fall and 1 in 20,000 probability of fall. Dust contamination as applied to other floor surfaces show commando sole performing above 35 PTV with all floor surfaces. Porcelain tiles, when wet, are able to maintain above low slip potential with leather, commando and rubber camp soles but with high slip probability with others. Also, Porcelain tiles have high slip probability when contaminated with dust. From the findings, it is clear that slip fall can occur if the foot wear is not appropriate with the surface conditions. In developing countries, selecting the appropriate slip-resistant footwear is severely challenged, because of non-existent of data. Further investigation is needed for various footwear soles available leading to developing database for public education in avoiding slip falls.

Subjects: Mechanical Engineering; Building and Construction; Occupational Health and Safety

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PUBLIC INTEREST STATEMENT

Slip fall is a dangerous occurrence both in home and work places as well public arena. Slip falls could be minimised if not eliminated with precautionary actions in place. However, technical information is required for such actions. In developing countries like Ghana, data on slip-resistant footwear are severely lacking. This paper is foundation paper in the context of a Sub-Saharan African Economy towards addressing this knowledge gap. Although exploratory, the findings offer understanding of the types of footwear that offer great opportunity for slip-fall resistant in a developing country context, where “second hand” or “used” shoes are predominantly in use. The findings provide bases in upscale research in this area for public education in avoiding slip falls and aiding design considerations of floors in Ghana.
Keywords: Slip fall; Pendulum test; floor surface finish; footwear sole

1. Introduction
Slip fall is an occurrence that arises from bodies loosing traction between their surfaces in contact, leading to a fall of the ungrounded body such as human being. For humans in contact with floor surface, slip fall, normally, occurs when the floor is wet or contaminated and also when the sole of footwear is not able to achieve the right traction (Grönqvist, 1995) A slip, therefore, represents the loss of balance caused by too little friction between the sole of a shoe and the walking surface. It can, therefore, be said that slips are primarily caused by a slippery surface and compounded by wearing inappropriate footwear. Slip resistance of a surface depends on the squeeze film and the contact pressure effect between the soling material and the floor (Grönqvist, 1995). To this extent, Chang, Kim, et al. (2008) provide further evidence to the effect that, in the last two decades, research has revealed that the microscopic roughness of floor surfaces and shoe solings has a profound effect on underfoot friction.

According to the U.S. Bureau of Labour Statistics (2019), slip falls accounted for the third greatest proportion of fatal injuries (19%) in all private and governmental industries across the globe. In certain occupational groups and industries, slip falls constitute the first or second largest proportion of total injuries. These incidents are expensive in both loss of productive working days and worker's compensation cost. Slip falls had been identified as one of the top five causes of workers' compensation claims over a six-year period in the past. Second to motor vehicle accidents, slip falls are the most frequent accidents leading to personal injury as reported by Pillo 2003. Slip falls can result in head injury, back injury, broken bone, cut and laceration, sprained joint or strained muscle and death. In Ghana, Blankson et al. (2019) reported that, out of the 17,860 presented cases in Ghana's main referral hospital, the Accident Centre of the Korle-Bu Teaching Hospital, from January 2016 to December 2017, 19.7% injuries were due to falls resulting in 13.7% of deaths. However, the mechanism of fall in the report was not clear. Udofia et al. (2019) also reported that a survey conducted with 3,530 respondents of 50-year-olds and above in Kumasi, Ghana, 51% injuries sustained were due to falls. These high numbers call for further investigation into the possible causes of falls resulting in such injuries and death, especially as reported by Blankson et al. (2019).

Slip may occur in two ways as suggested by Sigler et al. (1948, p. 1). When the forward foot make contact the walking surface at an angle near the edge of the heel. With this type of slip, the front foot slips forward and the person falls backward. 2). When the rear foot slips backward. With this type of slip, the force to move forward is on the sole of the rear foot. As the rear heal is lifted and the force move forward to the front of the sole, the foot slips back resulting in a fall. Some of the factors that can contribute to slip fall are: a foreign object on the walking surface; a design flaw in the walking surface; a slippery surface; an individual's impaired physical or condition. The slippery conditions may be such as ice, wet spots, grease, polished floor, loose flooring or carpeting, uneven walking surface, clutter and electrical cord. Loose irregular surface such as gravel, shifting floor tiles and uneven sidewalk can also make it difficult to maintain footing. Kim and Nagata (2008) also suggests slips falls are very common causes of injuries and fatalities in industry and to control such falls, there is the need to have an understanding of complex array of factors including the characteristics of footwear, gait dynamics, walking and working surfaces, and environmental conditions. Considering the stated causes, most slip fall incidents may be preventable with general precaution and safety measures regarding the use of the type of sole for the footwear. In regards to the surface pair, the cause of slip fall is varied and may be due to: surfaces that are wet, oily or dusty, weather condition and inappropriate footwear. These conditions can be termed as maintaining inappropriate friction between the two relative surfaces (floor surface and the footwear surface). Having the right amount of friction between the floor and the sole of the shoe of the person walking is therefore essential.

According to the literature, slip resistance properties are widely measured as a form of coefficient of friction (COF) index focusing on interface between the shoes and floors (Chang, Kim, et al., 2008; Kim & Nagata, 2008). Notwithstanding this, the literature also admits that
there is controversies surrounding the friction measurement as a format of COF index and the need for improvements in the principal concepts and methodologies (cf. Chang, Kim, et al., 2008; Kim & Nagata, 2008). Slip and fall happen when the coefficient of friction (COF) between two surfaces is insufficient. Typically, rough surfaces like brushed concrete or carpet have a higher COF than smooth surfaces such as polished marble, tile or wood. Dry surfaces also generally have a higher COF compare to wet ones. Thus, when attempting to decrease the likelihood of slip and fall in a workplace, increasing the COF of walking surfaces is often part of the solution. Footwear acts as medium between the foot and the ground. The function of footwear is to provide protection, safety, comfort and enhance performance during dynamic or static activities. The type of footwear worn can cause or prevent slip fall. Li et al. (2012) suggested that effects of all footwear, surface condition and inclined angle of the floor and their interactions are significant in fall. Chang, Kim, et al. (2008) had also stated that the need for improve methods for reliable slip resistance properties is highlighted in the literature. To this they argue that “While controversies around the friction measurement for slipperiness assessment still remain, surface roughness measurement may provide an objective alternative to overcoming the limitations of friction measurements”.

In developing countries like Ghana, however, much has not been done to understand the footwear and surface interaction with associated risk, and remedial measures thereof. Many developing countries rely on second-hand and low-quality footwear for economic reasons (Wetengere, 2018) including Ghana. This exploratory study is aimed at investigating the potential of slip of various floor surface finishes with footwear in selected public places in Kumasi, Ghana. The findings will be useful in understanding the role “used” or “worn-out” footwear play in causing slip falls, the risk thereof and measures to put in place to prevent fall in public places. It is earlier alluded in the literature suggesting that despite increasing research in slip resistance in the last two decades (cf., Kim & Nagata, 2008), there still remains controversies in improving testing and building the data base. Cockayne et al. (2021) has indeed very recently supported this position stating that while previous studies suggest that slip-resistant footwear can prevent slips, “it can be challenging to identify appropriate slip-resistant footwear due to the lack of robust testing and reliable information on which to base a decision.” In this context, therefore, this study was focused on understanding the intricacies of the friction and wear phenomena between the shoes and floors towards also contributing to building a robust knowledge base but in a developing country context, where second hand shoes are commonly used on floors that lack design specifications guiding slip floor.

2. Materials and Method
As indicated earlier, the occurrence of slip fall is due mainly to the relationship between floor surface and the sole material. This investigation involved simulation of possible conditions of the surface pair that makes up the tribo-system and estimating COF of the system. Various floor surfaces are selected and a number of sole materials identified with conditions and testing technology also chosen. These are further explained below.

2.1. Floor Surfaces
In Ghana, various floor surface finishes are in use. However, since the beginning of the new millen-nium, especially, most building floor surfaces are finished with tiles of different kind (Lucht, 2019; Smith, 2011). The development in the construction industry in Ghana, spurring increasing use of tiles for floor finishes. These tiles may range from Quarry tile (extensively used for floors where durable material is required and usually used in a sunroom, entryway, or even a kitchen), Rustic tile (used in a variety of home applications), Marble tile (porous and can be stained, scratched and worn easily), Ceramic tile (typically made from red or white clay and used in several areas throughout the building) and porcelain tile (a type of vitrified tile made from more dense ceramic material and also popular with homeowners). Other commonly known floor finished materials are Acrylic and Terrazzo tiling. These surface finishes may all be considered as potential for slip fall at various places, especially in public buildings if appropriate conditions are not maintained. In the area of interest, ten facilities with eight types of floor surfaces were selected. The floor surface finishes are: quarry tile, rustic tile, marble
tile, porcelain tile, ceramic tile, acrylic painted and terrazzo. Here, cement and sand screed, though not technically a tile floor finish, have been included as a control measure. This is because cement and sand screed have been a traditional floor finish with long history before tiling emerged for use in floor finish construction in the late 1980s and/or early 1990s (Schenkenbach & Abankwo Jackson, 1984). Indeed in housing projects, cement and sand screed are still popular with, especially, low income earners. Table 1 displays facilities with respective floor surface finishes that were used as unit of analysis for the study.

According to Bowman (2020), floors must be designed to be slip resistance with guiding principles that will make the floor safe and at the same time useful throughout its economic life cycle. This means such floors would have to be designed and constructed to meet appropriate building codes for especially commercial and public areas. Ghana currently launched a comprehensive building code for the construction industry in 2018. However, guides relating to slip falls have not clearly defined, as a result of the non-availability of test data. As noted by Bowman, apart from economic and structural benefits, there is the need for reliable data for the purposes of slip resistance requirements in building codes. The significance of this study again lies in the fact that, it would be the beginning of providing some test data for slip falls in Ghana that may be used in engendering and building requisite codes relating to slip resistance in the construction industry.

2.2. Sole Material of Footwear

The risks associated with slipping and falling are related to the material surface of footwear/floor surface, contamination condition and the geometric design of the sole (Li et al., 2006). Shoe soles of various tread design are very common. Tread pattern of the shoe affects friction, especially, under liquid-contaminated conditions. Verification of the effects of tread groove depth is significant in assisting designers in designing proper footwear for workers exposed to slippery conditions (Li et al., 2006). Sole material samples, in this exploit, are prepared in stripes to fit the testing equipment. As such, tread pattern influences are insignificant. For this initial investigation, five types of sole materials that are, apparently, in common use among youths and adults in Ghana were selected. These are Rubber camp, Leather, Raw cord, Commando and Rubber (Figure 1). The sole holders are produced from aluminium by die casting, filing to smoothen the surface. Holding hole is drilled and the sole sample is attached by using polyurethane glue adhesive, which is water- and heat-resistant to bind the sole unto the metal surface (Figure 2).

2.3. Instrumentation and Testing

Coefficient of Friction (COF) of a surface can be estimated with an apparatus generally refer to as the tribometer. The higher the COF value, the better the friction is between the two surfaces. The COF estimated usually reflects the condition of the surface when the measurement is taken. The floor may have a high COF when it is dry, but be very slippery when wet. Occupational Safety and Health Administration (OSHA) recommend a COF of 0.50 on dry surfaces (Nemire et al., 2016), but does not specify the method to be used for testing. The Americans with Disabilities Act (ADA), also recommend a COF of 0.60, (Sotter et al., 2005) but like OSHA, no test method is specified. One recommended slip testing method is the pendulum test as specified in British Standards to assess slip-risk. A pendulum test device (Figure 3A), as specified in BS 7976–2:2002 + A1:2013. The pendulum apparatus simulates the action of a foot on the walking surface. It is designed to replicate a pedestrian heel strike, the point at which most slips occur. Its operation is based on the Izod principle. In operation, a pendulum of a known mass rotates about a vertical spindle. The head of the pendulum is fitted with sample sole surface (Figure 2). When released from a horizontal position, the pendulum head strikes the sample surface with a constant velocity. The distance travelled by the pendulum after striking the sample surface is determined by the friction resistance of the surface. The skid resistance values, which, approximately correspond to the coefficient of friction multiplied by 100 (Clarke et al., 2015) are read directly from engraved scale. The pendulum results are referred to as Pendulum Test Values (PTV) or Slip Resistance Values (SRV). Table 2 illustrates the PTV as with UK Health and Safety Authority interpretation and
Figure 1. Sample footwear sole types.

A: Rubber camp

B: Leather

C: Raw cord

D: Commando

Figure 2. Picture of sole holder with sample.
slip probability. The apparatus used is the Stanley Munro Portable Skid Resistance Tester captured in Figure 3B.

Testing is done by initially levelling the pendulum tester by adjusting the three leg bolts at its base. This is then followed by raising the head unit so that the pendulum arm swings clear of the floor surface. The zero setting is checked and the pendulum arm raised to the horizontal release position. In this position, it is automatically locked in the release latch. The pointer is then brought to its stop in line with the pendulum arm. The pendulum arm is released by pressing the release button and will be caught on its return swing. Pointer reading is taken and the arm is again returned to release position.

To accurately set the sliding length of the surface, the pendulum arm is gently lowered until the sole sample slider just touches the surface first on one side and then on the other side of the vertical with a sliding length of between 125 mm and 127 mm (Clarke et al., 2015). The sliding
| No. | Type of Facility | Description and use | Floor surface finish |
|-----|------------------|----------------------|----------------------|
| 1   | Laboratory       | Engineering and technical experiment facility at Kwame Nkrumah University of Science and Technology, Kumasi. | Quarry tile |
| 2   | Classroom        | Large classroom with seating capacity of about 200 at the Kumasi University of Science and Technology area | Rustic tile |
| No. | Type of Facility | Description and use                                                                 | Floor surface finish |
|-----|-----------------|--------------------------------------------------------------------------------------|----------------------|
| 3   | Shopping Mall   | Large international shopping mall in the business centre of Kumasi, the second largest city in Ghana. | Marble tile          |
| 4   | Washroom        | Place of convenience in classroom environment in University.                           | Ceramic tile         |
| No. | Type of Facility | Description and use | Floor surface finish |
|-----|------------------|---------------------|---------------------|
| 5   | Auditorium       | A facility with 1,500 seating capacity in a University Environment | Ceramic tile       |
| 6   | Library          | Facility in University with 1,500 seating capacity and total stock of over 300,000 volumes | Porcelain tile     |

(Continued)
| No. | Type of Facility | Description and use | Floor surface finish |
|-----|------------------|---------------------|---------------------|
| 7   | Apartment        | “Homestel” facility for student accommodation with capacity of 15 to 25 occupants | Cement screed       |
| 8   | Office reception | Main administration facility in a University Environment with student population of over 50,000 | Acrylic painted     |
| 9   | Student residence | Hall of resident in a University Environment with population of 15,000 | Polished terrazzo   |
Table 2. PTV slip potential and probability for straight walk (health and safety authority, UK)

| Potential for slip | PTV Slip resistance test reading | Probability of slip |
|-------------------|---------------------------------|---------------------|
| High              | 0–20                            | 1 in 2              |
| High              | 20–24                           | 1 in 20             |
| Moderate          | 25–27                           | 1 in 200            |
| Moderate          | 28–35                           | 1 in 20,000         |
| Low               | 36 and above                    | 1 in 1,000,000      |

distance marked out on a gauge to ensure consistency. The sliding length is the distance between the two points where the working edge of the slider touches the test surface. The test was performed with each floor surface, footwear sample and floor condition (dry, wet and contaminated) making up the tribo-system. In other to minimise the effect of random error on the result, each test was carried out 3 to 5 times for an average value of PTV reading.

3. Results
The tests were performed based on three surface conditions: dry, wet and contaminated. The contaminated conditions are of two kinds. Dust contamination at social places (lecture area, library, shopping area, office and residence) and oil contamination at laboratory floors. Five types of footwear soles were used with respect to each floor type. The test values, PTV, are interpreted with respect to potential for slip as presented in Table 2.

The plot of the PTV values of the test are as in Figure 4. From the figure, when the floor surface is dry, all footwear soles have low probability of slip fall. This means that, all surfaces when dry met the safety requirement against slip fall. However, the results of contaminated floor surfaces have varied situations. Oily contamination applied to the laboratory environment generally indicated PTV results below 35. With raw cord and rubber camp, the PTV are below 24, meaning that oil contaminated floor surfaces are high risk for slip fall. The footwear sole material surfaces that show better performance are leather, commando and rubber. Their PTV of about 30 indicates moderate risk in slip fall and 1 in 20,000 probability of fall. Dust contamination as applied to other floor surfaces show commando sole performing above 35 PTV with all floor surfaces. In the case of wet surfaces, raw cord and rubber soles are bad performers with all floor surfaces. Rustic tile, when contaminated with dust maintain slip resistant above acceptable level with all sole types but can only perform well with leather sole when wet with water. Porcelain tile, when wet, are able to remain above low slip potential with leather, commando and rubber camp soles but with high slip probability with other soles as well as when contaminated with dust.

4. Discussion
Slip occurs when there is less traction between surfaces in contact and, in this case, when the footwear sole and the floor have less traction. Other reasons such as contaminants on the floor surface, polished floor surface and inappropriate sole, all may result to slipping by lowering traction or friction. Slip fall can result in injury and incapacitation and even lead to death. In developing countries like Ghana, records are not readily available to ascertain any direct slip fall related injury. The available data, however, as reported by Blankson et al. (2019) gave the general fall related data. Result of this research, which is an exploratory and a preliminary, indicated the dry condition of floor surfaces as safe conforming to information by Safety Direct America irrespective of footwear sole type. The risk is mostly associated with wet and contaminated surfaces comparing favourably to what is reported by Li et al. (2007). The wet condition in combination with footwear types like raw cord could be very risky as it has high slip potential. Slip fall can be avoided by making floor surfaces, footwear soles and conditions appropriate. Maintaining dry condition of the floor will always eliminate or minimise slip fall as observed from the test results. For every floor surface, the appropriate choice
of footwear sole can also help to reduce slip fall potential. The slickness of the soles and the types of heels worn need to be further investigated and evaluated with respect to the floor surface finish; polished terrazzo, quarry tile, marble tile, acrylic painted surface, cement screed surface and porcelain to avoid slip fall. With the current knowledge of footwear relationship with floor condition, and further research to be conducted, public safety education on slip fall at various places could be conducted. Chang, Gronqvist, et al. (2001), have noted that currently over 70 machines have been invented to measure slip resistance. However, none of them accurately represents the motion of a human foot and also, at present, there is no generally accepted method of measuring slipperiness. This suggests that further research could be conducted in instrumentation and methods of measurement in developing countries, as well. On the surface roughness consideration, the result presented here is limited and call for more investigation especially with the “used” footwear surfaces that are prevalent and well patronised in developing countries.

5. Recommendation and Conclusion
The types of floor surface finish investigated were quarry tile, rustic tile, marble tile, porcelain tile, ceramic tile, acrylic painted and terrazzo. The sole materials considered were leather, rubber, commando, raw cord and the rubber camp. The classes of slip included high slip potential, moderate slip potential, low slip potential and extremely low slip potential. For this study, oil and dust were used as contaminants, water was used for the wet condition and the dry condition was just the bare surface finish. Further investigation may involve more contamination conditions. From the findings, slip fall potentials can be managed to minimum if not complete elimination by putting the right measures in place. Failure to be conscious of slip fall potential condition of a place can result in fatal, life-threatening accident both at home and at the workplace. Further investigation may also consider other footwear soles available for a much deeper understanding and validation. However, the current data offer some opportunity to use the findings for public education to avoid slip fall effects within the community of interest.

Acknowledgements
Authors will like to acknowledge the contributions of Mr. Richmond Selasie Klimago, Mr. John Koomson and Mr. Cephas Kudalor who undertake the testing as their final year project for BSc. Degree in Mechanical Engineering at the Department of Mechanical Engineering, KNUST.

Funding
The authors received no direct funding for this research.

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Disclosure statement
No potential conflict of interest was reported by the author(s).

Citation information
Cite this article as: Slip conditions of floor surface finish in selected public places in Kumasi, Ghana, Yesueneagbe A. K. Fiagbe & Divine K. Ahadzie, Cogent Engineering (2022), 9: 2026205.

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