Health and Safety Executive

Optimisation of the mechanical slip resistance test for footwear used in EN ISO 13287:2007

Follow on study

Prepared by the **Health and Safety Laboratory** for the Health and Safety Executive

RR951
Research Report

HSE

Health and Safety
Executive

Optimisation of the mechanical slip resistance test for footwear used in EN ISO 13287:2007

Follow on study

Miss Alison Darby
Harpur Hill
Buxton
Derbyshire
SK17 9JN

The measurement of the slip resistance of footwear is inherently difficult due to the complexity of the human gait, which leads to changing values of the biomechanical parameters during the walking step. Only some steps result in a slipping heel, which compounds the difficulty in identifying the values of the parameters that need to be simulated. A number of studies have attempted to measure the parameters of walking and/or a slip, in order that realistic values can be incorporated into tests attempting to replicate the slip process.

This report and the work it describes were funded by the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the author alone and do not necessarily reflect HSE policy.

HSE Books

EXECUTIVE SUMMARY

The current International and European Standard test method for the assessment of the slip resistance of footwear is BS EN ISO 13287: 2007 Personal Protective Equipment – Footwear - Test Method for Slip Resistance. The test, which is mechanical, operates by lowering a sample of footwear onto a horizontal surface, upon which a contaminant is usually applied. A vertical force is applied to the footwear and, after a short static contact time, the floor surface and the footwear are moved horizontally relative to one another, through a fixed distance and at a constant speed. The horizontal force needed to move the floor surface is recorded, and a measurement of slip resistance is generated.

The Health and Safety Laboratory (HSL) has concerns that the mechanical test does not accurately replicate the friction involved in a pedestrian slip, when operated using the values for the test parameters currently in BS EN ISO 13287:2007. HSL uses a human subject-based ramp test method, HSL SOP-12, to assess the slip resistance of both floor surfaces and occupational footwear. This method involves at least two human operators wearing the test footwear and carrying out a series of controlled walks over a standard floor surface, upon which contaminant is applied. The ramp method is effective in discriminating between footwear, and results have proved useful in selecting footwear that reduces the occurrence of slip accidents (Thorpe et al, 2003). The mechanical test would offer a more versatile and economical method of measuring slip resistance than the ramp test if it could be modified so that it replicated a slip more accurately. (Note: Slip resistance is usually expressed as coefficient of friction.)

Initial work (Hunwin et al, 2010) had indicated that it was possible to bring coefficients of friction measured by the mechanical test into closer agreement with those from the HSL ramp test by modifying the values of the mechanical test parameters. The 2010 work considered only one test mode and three surface /contaminant combinations.

This study followed up the initial work by considering an additional surface / contaminant combination, and an additional (the flat) test mode of the standard mechanical test. The aim was to identify a set of optimised values for the parameters of the mechanical test. The optimised values would be used in a concurrent project (Darby et al, 2012) investigating workplace accidents where the injured person was wearing CE marked slip resistant footwear. It was intended to re-test the incident footwear using the parameter values currently in BS EN ISO 13287: 2007 to determine whether the footwear would have still met the CE criteria for slip resistance at the time of the accident (that is, in the worn state). The incident footwear would also be tested with the optimised values for the test parameters established by this project.

Main Findings

The values of the parameters used in the mechanical test could not be optimised to bring the measured coefficients of friction into good agreement with those from the HSL ramp test.

The mechanical test did not discriminate between different footwear in the same way as the HSL ramp test.

The mechanical test coefficient of friction was sensitive to a small change in the vertical force. Furthermore, the degree of change in coefficient of friction varied from footwear model to footwear model.

CONTENTS PAGE

1. INTRODUCTION

1.1 BACKGROUND

The measurement of the slip resistance of footwear is inherently difficult due to the complexity of the human gait, which leads to changing values of the biomechanical parameters during the walking step. Only some steps result in a slipping heel, which compounds the difficulty in identifying the values of the parameters that need to be simulated. A number of studies have attempted to measure the parameters of walking and/or a slip, in order that realistic values can be incorporated into tests attempting to replicate the slip process.

Strandberg and Lanshammar (1981) proposed that any test to measure slip resistance should replicate, as closely as possible, the parameters of slipping. They stated that important parameters are the angle of the foot, the point of application of the contact force through the footwear, the magnitude of the vertical force, the sliding force, and the time scale. Fischer included the walking velocity, the velocity of the heel at heel contact, and contact area of the shoe sole as significant parameters (Fischer et al, 2009). Grönqvist (1999) identified the slip speed, the vertical force and the static contact time as the important parameters.

The current International and European Standard test method for the assessment of the slip resistance of footwear is BS EN ISO 13287: 2007. The test conditions and slip resistance requirements (expressed as coefficient of friction (CoF)), with regard to safety, protective and occupational footwear, are defined within an amendment to the series of standards relating to personal protective equipment, BS EN ISO 20344:2004/A1: 2007, BS EN ISO 20345: 2004/A1: 2007, BS EN ISO 20346: 2004/A1: 2007, and BS EN ISO 20347: 2004/A1: 2007.

The method and test parameters are based upon biomechanical studies of walking and slipping in which force platforms were used to measure the horizontal (H) and vertical (V) forces applied during walking (Perkins, 1978). From traces of the ratio of H/V forces, Perkins identified that the normal walking step was composed of three distinct phases. The Landing Phase, where the heel initially contacts the ground and the body weight is transferred to the leading foot; the stationary phase, where the foot is in flat contact with the surface, and the take-off (or toe-off) phase, where, initially, the forepart of the foot is in contact with the ground, but contact moves towards the toe as the foot pushes off the surface and body weight is gradually transferred to the opposite leg.

Peaks in the H/V traces indicated where in the walking step the horizontal friction requirement was greatest, and therefore a slip was most likely to occur. A large, broad peak in the shear force (H) occurred during the landing phase and this was where the frictional force requirement was highest. It occurred approximately 90-150ms after heel strike (Redfern et al, 2003). A smaller spike in the H/V trace was observed at the instant of heel strike (Redfern et al, 2003).

Perkins (1978) also carried out slip experiments, in which subjects wore rubber-soled footwear and walked over a stainless steel surface contaminated with oil. High-speed photography was used to study the motion of a 'slip at heel contact of the walking step', and relate the motion to the measured H/V force traces. Slips were differentiated by the way they commenced. A slip could start immediately after the heel contacted the surface, which would coincide with the spike observed in the H/V trace at heel contact. The continuous velocity of the heel in contact with the surface, suggested that dynamic friction between the footwear and surface influenced the probability of such a slip occurring.

A slip could also start a short time after the initial heel contact. The slip began approximately 50ms ((Strandberg & Lanshammar, 1981) to 100ms (Perkins, 1978) after heel contact, with the forepart clear of the floor surface, but the forepart would usually roll flat to contact the surface after a short time. The slip coincided with the measured vertical force through the heel reaching approximately 60% of the subject's body weight, or approximately 50kg (for a subject weighing 80kg) (Strandberg & Lanshammar, 1981). Fischer et al, 2009 support this figure with their finding that their maximum friction requirement occurred at a vertical force of 500N to 600N. Perkins and Wilson, 1983 concluded that static friction is a more relevant measure for a slip of this type, because of the short delay before the heel begins to slip.

The distance through which the heel slipped was significant in determining whether the subject lost balance, with slips greater than 10 to 15cm in length leading to a fall (Perkins 1978). Strandberg & Lanshammar, 1981 found that their slip experiments usually resulted in a fall, if the slip velocity of the heel exceeded $0.5ms^{-1}$ or continued for a distance greater than 10cm.

Chambers et al, 2002/2003 measured the mean heel contact angle. When a subject suspected or knew of slippery floor conditions, mean contact angles of 21.5° and 20° respectively were observed.

In the 1970s the Shoe and Allied Trades Research Association (SATRA) developed a laboratory-based test rig for the measurement of coefficient of friction, which attempted to replicate slip behaviour in the three phases of the walking step observed in Perkins' studies (Perkins & Wilson, 1983).

The test operates by lowering the footwear onto a horizontal sample floor surface mounted upon a motor drawn carriage. A pneumatic cylinder applies a vertical force to the footwear. After a short static contact time at full load (there is also some contact as the load is applied), the motor draws the floor surface through a fixed distance beneath the footwear at a constant speed. Two sensors measure the horizontal force generated by the resistance to motion between the sole of the footwear and floor surface. (This is the horizontal force needed to cause movement between the footwear sole and the floor surface.) The machine displays a trace of the measured horizontal force (H) divided by the vertical force (V), and the resulting measurement of coefficient of friction. The value of each of the test parameters is stipulated within BS EN ISO 13287:2007.

The current Standard requires a normal or vertical force of 500±25N for footwear of size 40 paris points or above, or 400±20N for footwear of less than 40 paris points in size. A static contact time of up to 1.0s is defined before initiation of sliding movement. The required slip speed is $0.3\pm0.03ms^{-1}$ during the measurement period (or snapshot), which is between 0.3s and 0.6s after the start of sliding movement. The slip distance is not defined within the standard, but measurements are normally carried out over a distance of 200mm. Further explanation of the test parameters is given within (Hunwin et al, 2010). The requirements are broad enough to allow other machines to meet the Standard (Grönqvist, 1989).

1.2 LUBRICATION THEORY

A number of different models to describe the interaction between the sole of the shoe and the floor surface during a slip have been discussed by Grönqvist (1999). Attempts to explain the formation of the lubricating film of contaminant generated by the heel during a slip were also reported by Proctor and Colemen (1988). A number of models have been based upon the hydrodynamic theory for a tapered wedge, described by Fuller (1956).

In the hydrodynamic lubrication of a tapered wedge bearing, the two surfaces between which the fluid film forms converge (Figure 1.1). If the inclined surface moves relative to the stationary surface below, which is covered with a lubricating fluid, the liquid is drawn into the converging gap between the surfaces. If the relative velocity of the two surfaces is sufficient, the hydrodynamic pressure generated within the fluid supports the load of the upper surface, reducing the contact between the two surfaces, and therefore reducing the friction between them. When the relative velocity is high enough, the thickness of the fluid film is enough to separate the two surfaces completely.

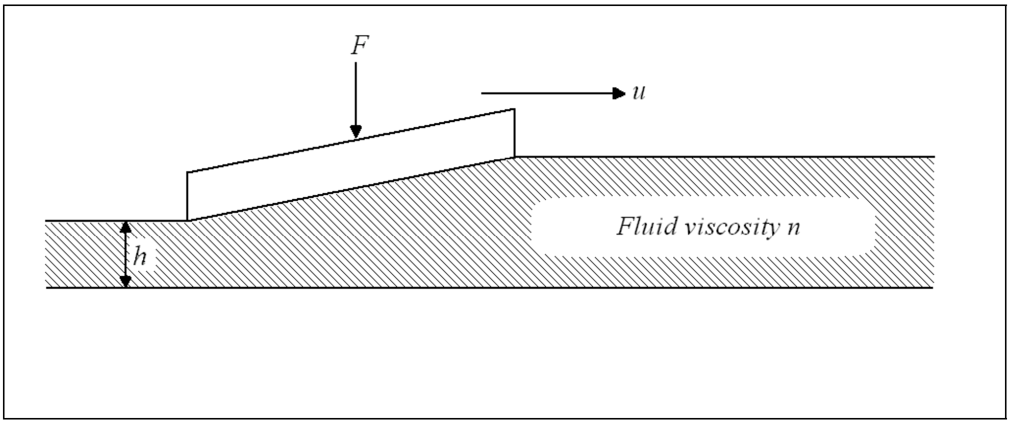

Figure 1.1 Formation of a fluid film

Although the theory strictly relates to the lubrication of two rigid surfaces, it is useful in understanding a pedestrian heel slip and the influence of the various parameters on the formation of a fluid film, and thus the measured coefficient of friction.

The equation describing the lubrication of a tapered wedge bearing is given below (equation 1). (In this simplified model it has been assumed that there is no deformation of the surfaces during the formation of the fluid film, as may be the case with the sole of a shoe.)

$$h^2 = \frac{6u\eta l^2 b K_E}{F_v} K_p \qquad (1)$$

where:

h = thickness of the fluid film at the exit of the converging surfaces

u = velocity of the bearing relative to the surface below

η = viscosity of the fluid

l = bearing length

b = bearing width

K_E = correction factor dependant upon the ratio of the bearing width to the bearing length

K_p = correction factor to allow for the pressure variation

F_v = vertical force

Equation 1 shows that the thickness of the fluid film increases as the relative velocity of the two surfaces, the viscosity of the fluid, and the dimensions of the bearing surface increase. It also shows that the thickness of the fluid film decreases as the vertical force increases. If this model is applied to a pedestrian heel slip or a device for the measurement of coefficient of friction, the vertical force, the relative velocity of the heel or slider to the floor surface, and the viscosity of the contaminant influence the coefficient of friction.

1.3 EN MECHANICAL TEST PARAMETERS

From the literature discussed in Section 1.1 and from lubrication theory, the slip distance and the measurement period used in the mechanical test are not thought to be significant with regard to the measured coefficient of friction. The static contact time, the applied vertical force and the slip speed are thought to be important parameters.

The maximum static contact time (1s) permitted in BS EN ISO 13287:2007 appears to be too long, but the 500N vertical force specified is in accordance with values given in the literature.

The 0.3ms^{-1} slip speed specified appears to be too low. A minimum slip speed of 0.5ms^{-1} would seem necessary to generate a realistic measure of a coefficient of friction with a low viscosity contaminant (such as water).

The Health and Safety Laboratory (HSL) has concerns that the mechanical test specified in BS EN ISO 13287:2007 does not accurately replicate the friction present at the time of a slip. HSL uses a human subject-based ramp test method, HSL SOP-12, to assess the friction offered by footwear on a contaminated surface. This method involves at least two human operators wearing the test footwear, The operators carry out a series of controlled walks over a standard floor surface upon which contaminant is applied. The ramp method is effective in discriminating between footwear, and results have proved useful in selecting footwear that reduces the occurrence of slip accidents (Thorpe et al, 2003). However the mechanical test potentially offers a more versatile method of measuring coefficient of friction for both floor surfaces and footwear, provided that it can be modified so that it replicates a pedestrian slip with sufficient accuracy. (For the purposes of this study, ‘sufficient accuracy’ is defined as the test results agreeing with those generated by the HSL ramp test. That is, the two tests discriminating between different footwear in the same way.)

Initial work (Hunwin et al, 2010) indicated that using different values for some of the mechanical test parameters improved agreement between the coefficient of friction measured and that measured with the HSL ramp test. However the study only considered one test mode and three surface / contaminant combinations, so it was limited in nature. The current study extends the work to a further surface / contaminant combination, and an additional (the flat) test mode. The aim of the study was to optimise the parameter values used in the mechanical test to obtain best agreement of the test results with those from the HSL ramp test.

2. METHODOLOGY

2.1 FOOTWEAR

Twelve models of footwear previously tested by HSL using the HSL Ramp Test method (HSL SOP-12) and found to offer different levels of slip resistance, were selected for use in the study.

The selected footwear was tested according to the HSL Ramp Test method again, in case significant changes in the footwear had occurred since the original ramp testing had taken place. The ramp testing was undertaken on two different floor surface / contaminant combinations. Footwear were tested on a water-contaminated stainless steel surface, and upon a fully vitrified ceramic tile surface, contaminated with glycerol. Further details of the HSL Ramp test method can be found in Hunwin et al, 2010.

2.2 TESTING TO BS EN ISO 13287:2007

The twelve samples of footwear were next tested with the mechanical test using the parameter values from BS EN ISO 13287:2007, but using the same combinations of surface and contaminant as the ramp testing outlined above (on a water-contaminated, stainless steel surface (surface defined within 6.4 of BS EN ISO 13287:2007), and the glycerol-contaminated, fully vitrified ceramic tile surface). Measurements of the slip resistance were made under the 7° heel test mode and the flat test mode, for each surface-contaminant combination. All footwear was of a size greater than 40 paris points.

The results were used to assess how well the coefficient of friction according to the ramp and EN test methods agreed. They were also used to select three samples of footwear of differing slip resistance performance for use in investigating the effect of modifying three test parameters, slip velocity, vertical force and static contact time, on the coefficient of friction measured.

2.3 MODIFICATION OF EN TEST PARAMETER VALUES

The three samples of footwear were used to investigate the effect of modifying the values of the test parameters believed to be the most influential in altering the fluid film, and thus the measured coefficient of friction. All tests were carried out on a stainless steel surface contaminated with water, with the footwear in the heel test mode.

Measurements of coefficient of friction for each footwear sample were made at vertical forces of 500N, 400N, 300N, 200N and 150N. (BS EN ISO 13287:2007 specifies a vertical force of 500N for footwear of this size.) All other test parameters were as specified within BS EN ISO 13287:2007.

Similarly, measurements of coefficient of friction were made at increasing static contact times of 25ms, 50ms, 100ms, 200ms, 300ms, 400ms, 500ms and 1s. (BS EN ISO 13287:2007 specifies a static contact time of up to 1s.) Again, all other test parameters were as BS EN ISO 13287:2007.

Finally, the effect of increasing the slip speed was investigated by measuring the coefficient of friction of the three samples of footwear at $0.1ms^{-1}$, $0.2ms^{-1}$, $0.3ms^{-1}$, $0.4ms^{-1}$ and $0.5ms^{-1}$. (BS EN ISO 13287:2007 specifies a slip speed of $0.3ms^{-1}$). To investigate the effect of slip speeds at $0.4ms^{-1}$ and $0.5ms^{-1}$, the snapshot (the period over which the measurement is taken) was adjusted (Hunwin et al, 2010). All other test parameters were as specified within BS EN ISO 13287:2007.

The findings from using the three models of footwear were used to inform further investigations using all twelve models. These tests are described within the Results section of the report.

3. RESULTS

3.1 COF ACCORDING TO BS EN ISO 13287:2007

The coefficient of friction for the twelve samples of footwear according to the EN test (but on the water-contaminated, stainless steel surface and on the glycerol-contaminated, fully vitrified ceramic tile surface) is plotted against the coefficient according to the HSL ramp test in figures 3.1 to 3.4. The first two figures show the coefficients of friction with the steel surface contaminated with water (heel and flat test modes). The latter two figures show the coefficients of friction for the vitrified ceramic tile surface (also known as Pavigrés) contaminated with glycerol (heel and flat test modes).

The dotted line on each graph is a 1 to 1 relationship between the two sets of data. (That is, if the coefficient of friction for a sample according to both test methods was identical, the data point would lie on the dotted line.)

The figures also have a horizontal line and a vertical line associated with each data point. The horizontal line shows the range of coefficients of friction found during the twenty ramp walks involved in each footwear test. The vertical line shows the range of coefficients of friction found in the ten measurements involved in each mechanical test.

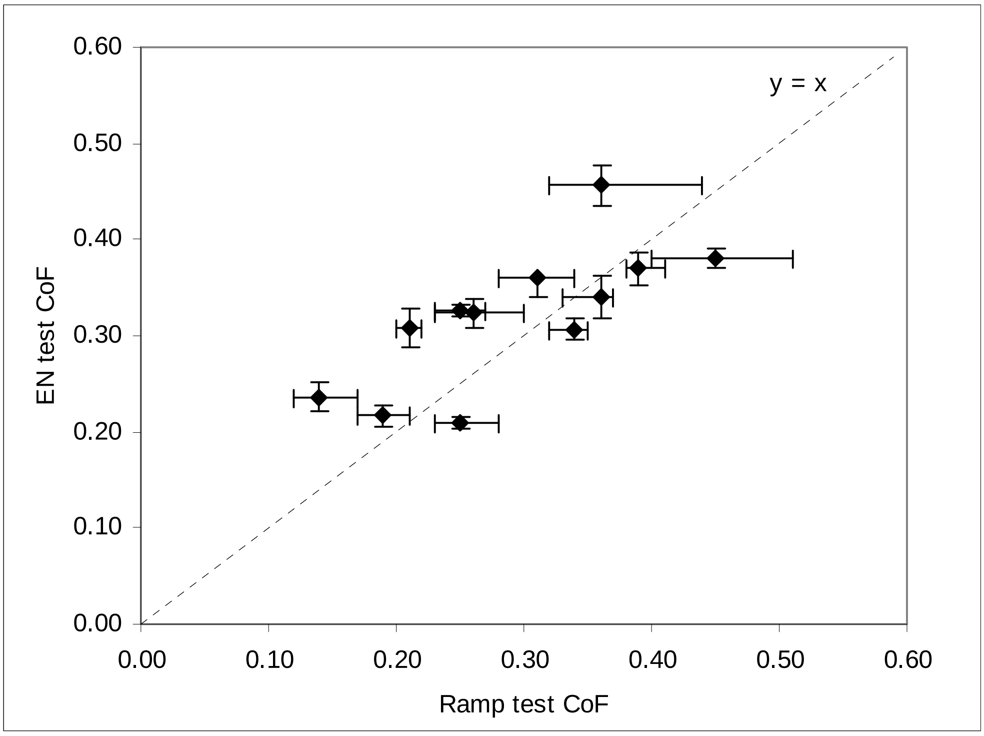

Figure 3.1. CoF according to the EN test and the HSL ramp test - heel test mode, stainless steel plate with water.

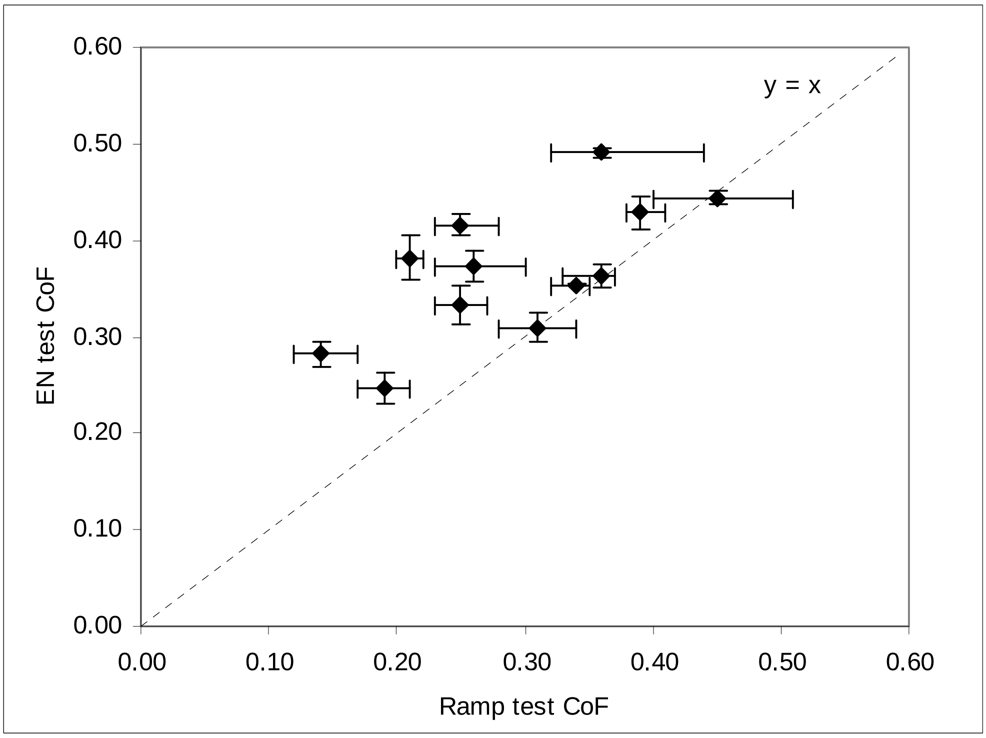

Figure 3.2. CoF according to the EN test and the HSL ramp test - flat test mode, stainless steel plate with water.

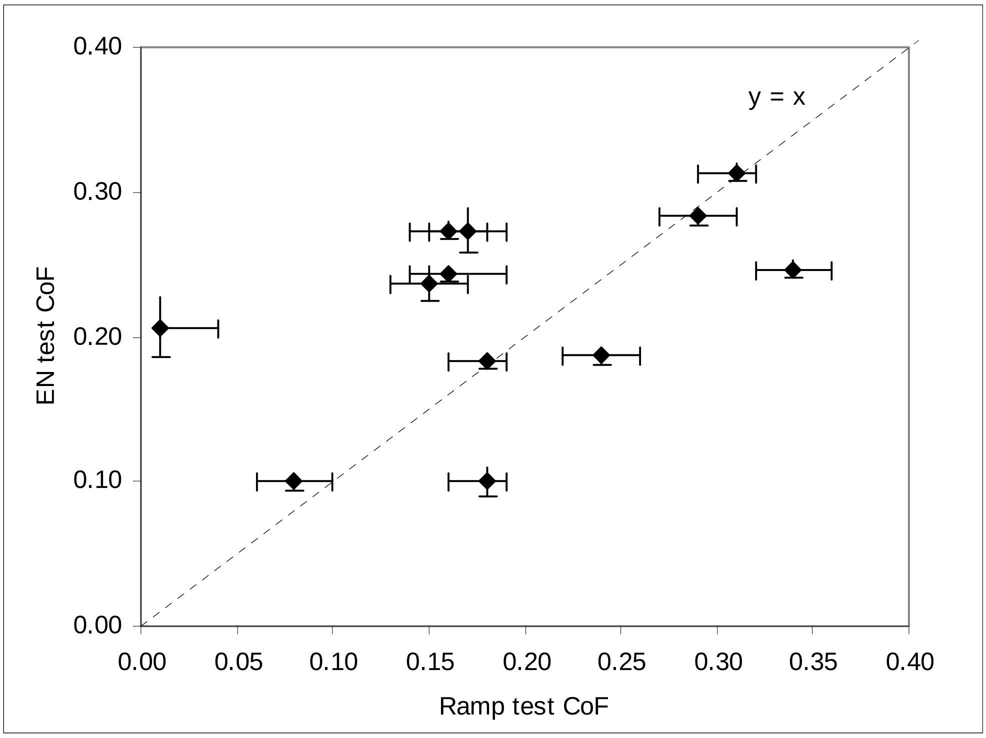

Figure 3.3. CoF according to the EN test and the HSL ramp test - heel test mode, vitrified ceramic with glycerol.

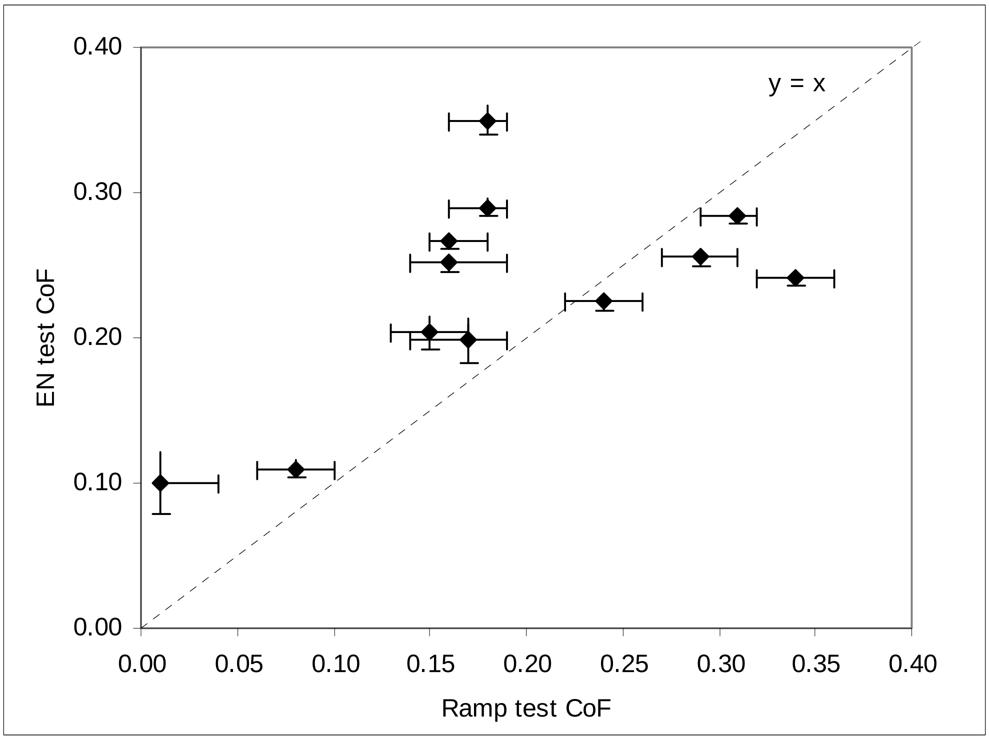

Figure 3.4. CoF according to the EN test and the HSL ramp test - flat test mode, vitrified ceramic with glycerol.

As can be seen from these figures, overall the coefficients of friction from the two tests were not in good agreement, even when the horizontal and vertical range bars associated with each data point were taken into account.

3.2 EFFECT OF ALTERING TEST PARAMETERS INDIVIDUALLY

3.2.1 Vertical Force

Figure 3.5 shows the coefficient of friction given by the mechanical test plotted against the applied vertical force, for the three samples of footwear. All other test parameters were as specified in BS EN ISO 13287:2007.

The results in figure 3.5 for the three selected samples of footwear, suggested that changing the applied vertical force on its own would have little effect on the measured coefficient of friction unless the force were reduced to a much lower value than that suggested in the literature. The coefficients of friction showed very little change until the vertical load was reduced to 150N, when, for two of the samples there was a moderate drop in its value.

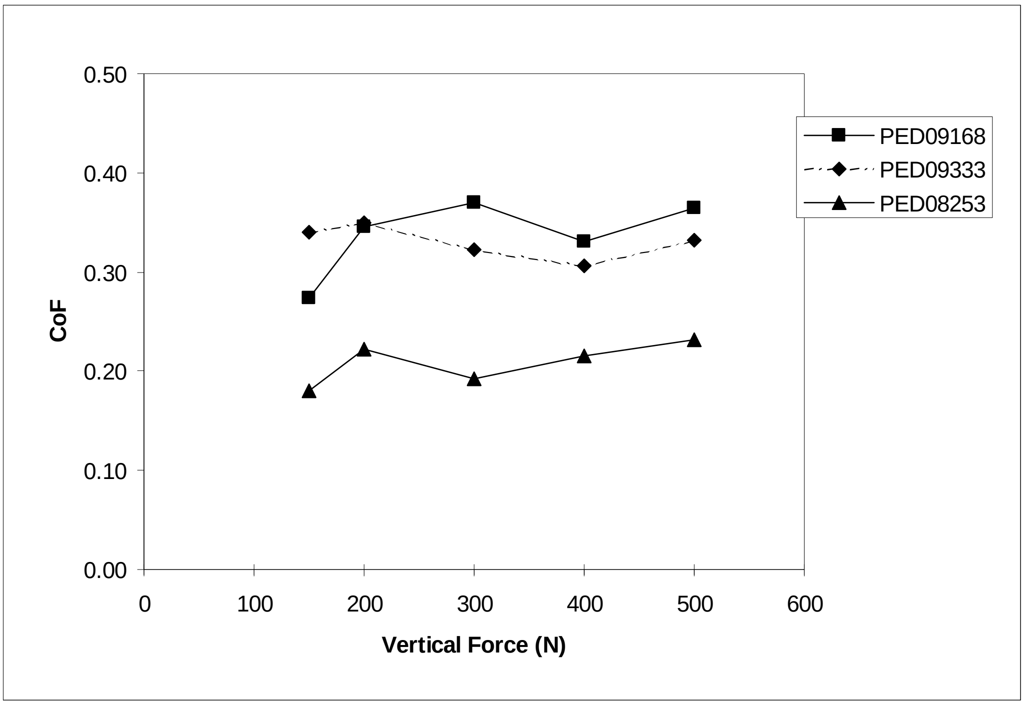

Figure 3.5. CoF with the mechanical test plotted against the vertical load - heel test mode, steel plate with water.

3.2.2 Static Contact Time

Figure 3.6 shows measurements of coefficient of friction plotted against the static contact time,. All other test parameters were as specified in BS EN ISO 13287:2007.

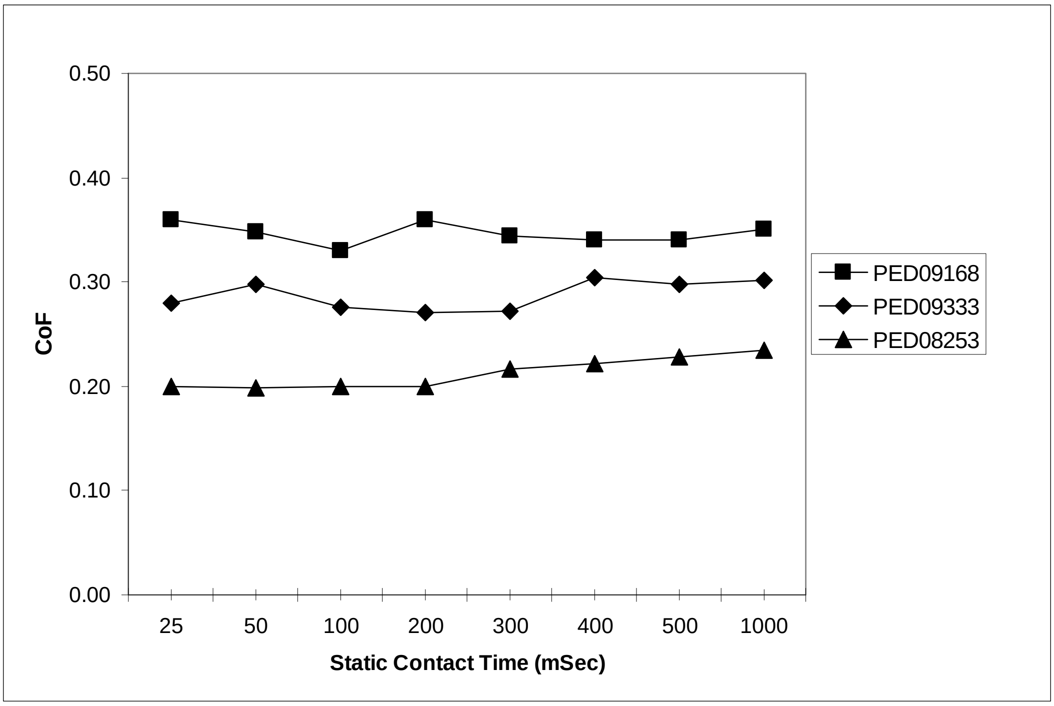

Figure 3.6. CoF with the mechanical test plotted against the static contact time - heel test mode, steel plate with water.

The results in figure 3.6 showed that for the three samples tested, altering the static contact time on its own had very limited effect on the measured coefficient of friction.

The measured coefficient of friction for sample PED/08/253 remained unchanged at static contact times up to 200ms. At static contact times from 300ms to 1s it showed a very small increase. The data for samples PED/09/168 and PED/09/333 showed a similar degree of variation in coefficient of friction but no trend with the increasing static contact time.

3.2.3 Slip Speed

Figure 3.7 shows the measured coefficient of friction plotted against slip speed for the three samples of footwear in the heel test mode, on a steel plate surface contaminated with water. All other test parameters were as specified in BS EN ISO 13287:2007, except for the snapshot, which was set appropriately as the slip speed increased.

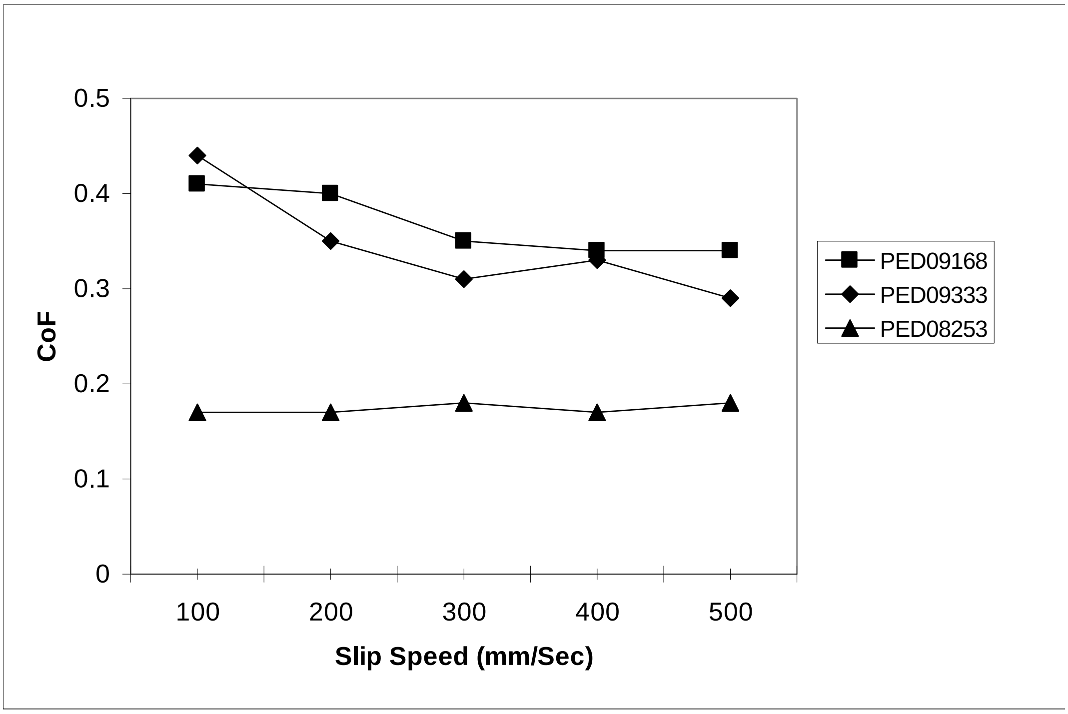

Figure 3.7. CoF with the mechanical test plotted against the slip speed - heel test mode, steel plate with water.

The data in figure 3.7 for the three samples of footwear showed that the measured coefficients of friction for samples PED/09/168 and PED/09/333 decreased significantly as the slip speed was increased from $0.1ms^{-1}$ to $0.3ms^{-1}$. This is in line with the theory in Section 1.2. Despite the soling pattern allowing the contaminant to be expelled from the sole-floor contact, the increasing slip speed creates enough hydrodynamic pressure in the contaminant for it to reduce the contact between the sole of the footwear and the floor surface, thus reducing the measured coefficient of friction.

The slip speed had little influence on the measured coefficient of friction of sample PED/08/253 over the range of speeds possible with the machine. This may be because the measured coefficient of friction for sample PED/08/253 was already low at the lowest slip speed used ($0.1ms^{-1}$).

These results indicated that the slip speed had the greatest influence upon the measured coefficient of friction. Consequently it was concluded that a slip speed higher than $0.3 \pm 0.03 ms^{-1}$ (the speed specified in the Standard) offered the most likely possibility of bringing a coefficient of friction from the mechanical test into closer agreement with that from the HSL ramp test.

Further assessments of the influence of the slip speed and the vertical force on the coefficient of friction measured with the mechanical test were then carried out on the larger sample of footwear to establish the effect of the parameters with greater certainty.

3.3 INFLUENCE OF VERTICAL FORCE AT A SLIP SPEED OF 0.4MS^{-1}

Initially, the twelve samples were tested at a slip speed of $0.4ms^{-1}$, at vertical forces of 500N, 400N, 300N and 200N. Measurements were made in the heel test mode, on the smooth steel surface with water contamination.

Figures 3.8 and 3.9 show the measurements for 500N and 200N vertical forces respectively, plotted against the corresponding coefficient of friction given by the HSL ramp test.

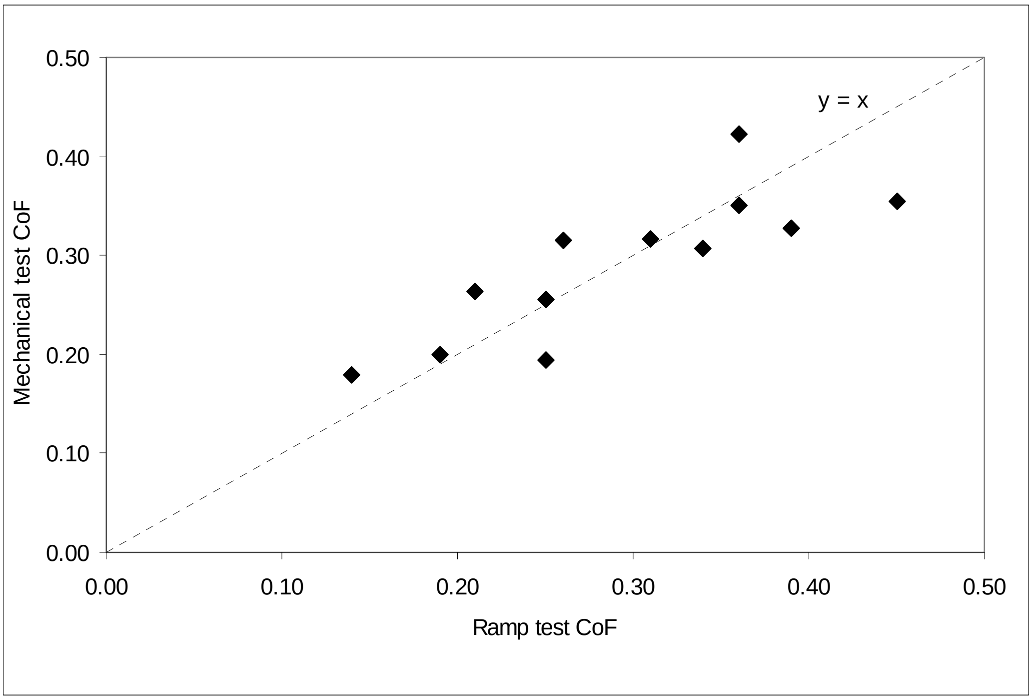

Figure 3.8. CoF with the mechanical test - heel test mode, steel plate with water, slip speed of 0.4ms^{-1}, vertical force of 500N

It was concluded from this part of the investigation that for most of the footwear tested the effect of reducing the vertical force (under these test conditions) was very limited. It was noted, however, that for two samples of footwear, a reduction in the vertical load had opposite effects on the coefficient of friction from the mechanical test.

Looking at figures 3.8 and 3.9, three of the samples of footwear had a very similar coefficient of friction (approximately 0.25) according to the ramp test. As the vertical force used in the mechanical test was reduced, the measured coefficient of friction for one of these samples reduced significantly, whilst it increased significantly for another. (It remained approximately the same for the third sample.)

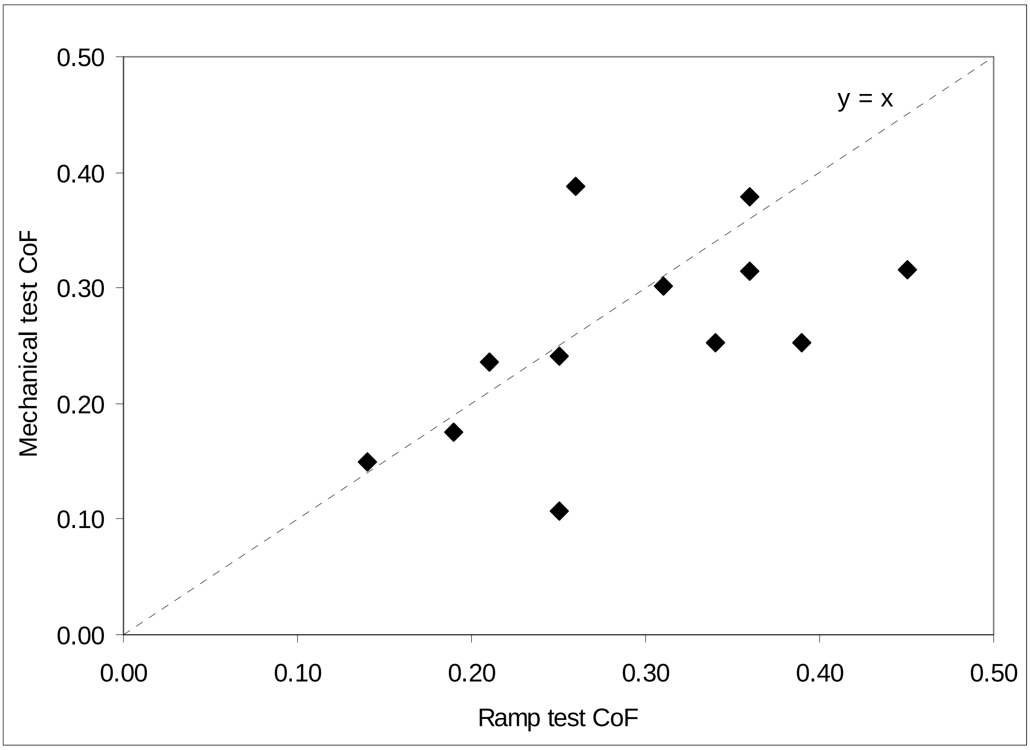

Figure 3.9. CoF with the mechanical test - heel test mode, steel plate with water, slip speed of 0.4ms^{-1}, vertical force of 200N

3.4 SLIP SPEED OF 0.5MS^{-1}, VERTICAL FORCE OF 500N

The twelve samples of footwear were next tested at a slip speed of 0.5ms^{-1}, the minimum value suggested by Strandberg & Lanshammar, 1981. The vertical force specified in BS EN ISO 13287:2007 (500N) was applied. Measurements were made in the heel and flat test modes, on the smooth steel surface with water contamination (figures 3.10 and 3.11 respectively) and on the vitrified ceramic tile surface contaminated with glycerol (figures 3.12 and 3.13 respectively).

It was concluded from this data that increasing the slip speed of the mechanical test did not bring the measured coefficients of friction into closer agreement with those from the ramp test.

From examination of figures 3.10 to 3.13 it became apparent that the mechanical test assessed a number of the footwear samples that had a very similar coefficient of friction according to the HSL ramp test as having very different coefficients of friction. The effect was particularly pronounced for vitrified ceramic / glycerol, the rougher surface and more viscous contaminant combination, but it also existed for the steel contaminated with water combination. The samples in question had a ramp coefficient of friction on vitrified ceramic / glycerol (figures 3.12 and 3.13) of approximately 0.15 to 0.17.

Further examination of the BS EN ISO 13287:2007 data in figures 3.1 to 3.4 revealed the same effect. The feature was particularly pronounced in figure 3.4.

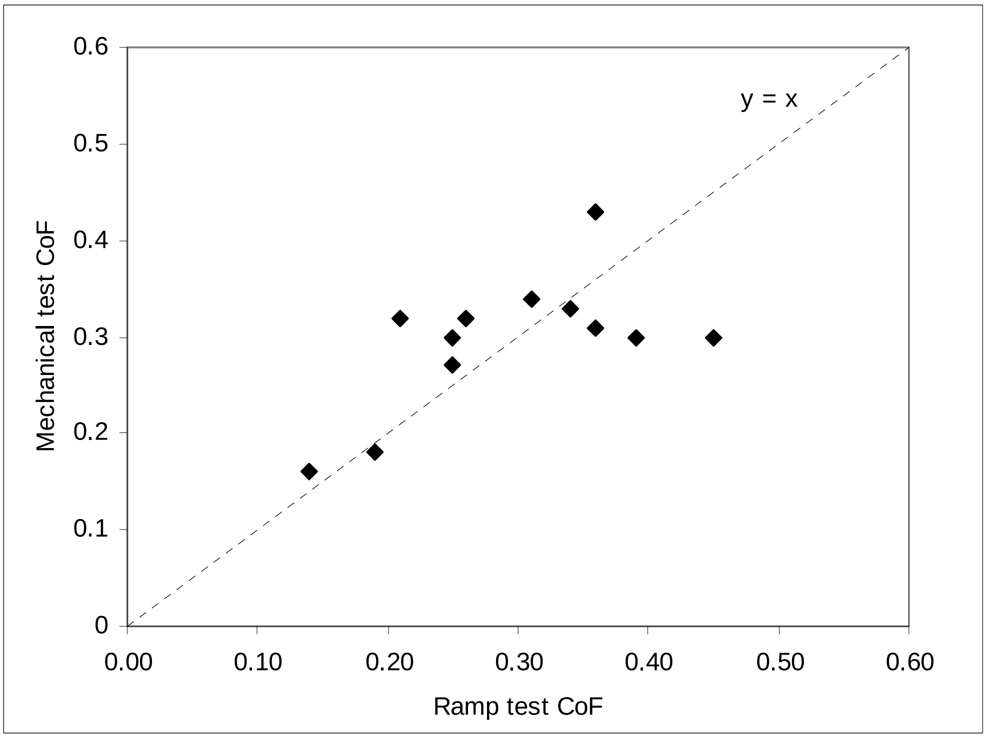

Figure 3.10. CoF with the mechanical test - heel test mode, steel plate with water, slip speed of 0.5ms^{-1}, vertical force of 500N

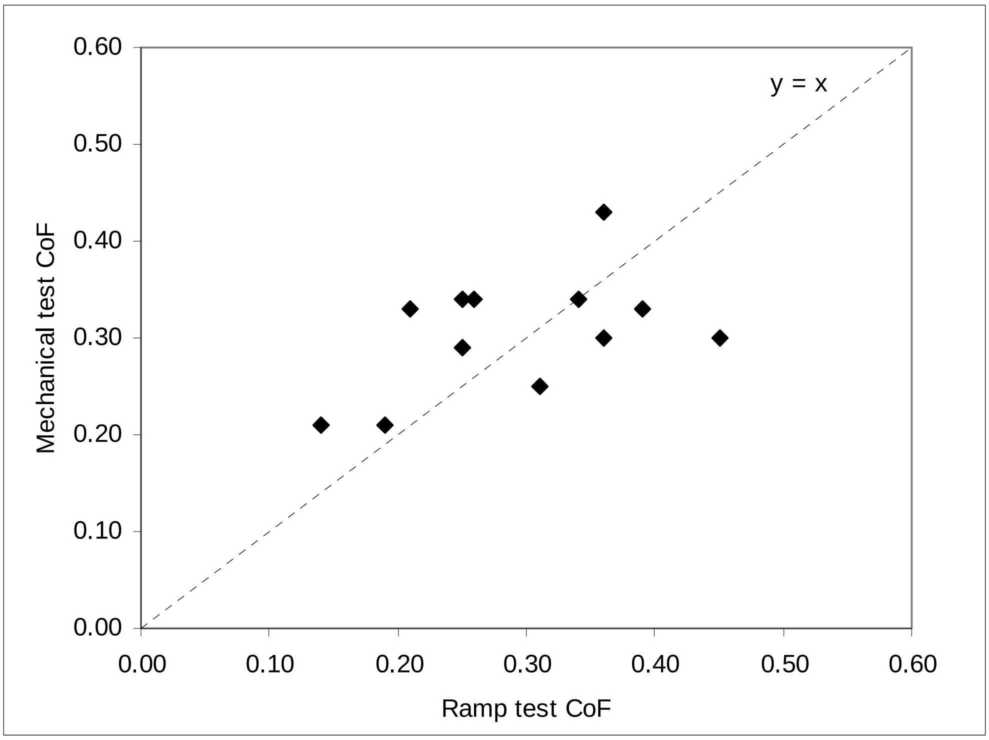

Figure 3.11. CoF with the mechanical test - flat test mode, steel plate with water, slip speed of 0.5ms^{-1}, vertical force of 500N

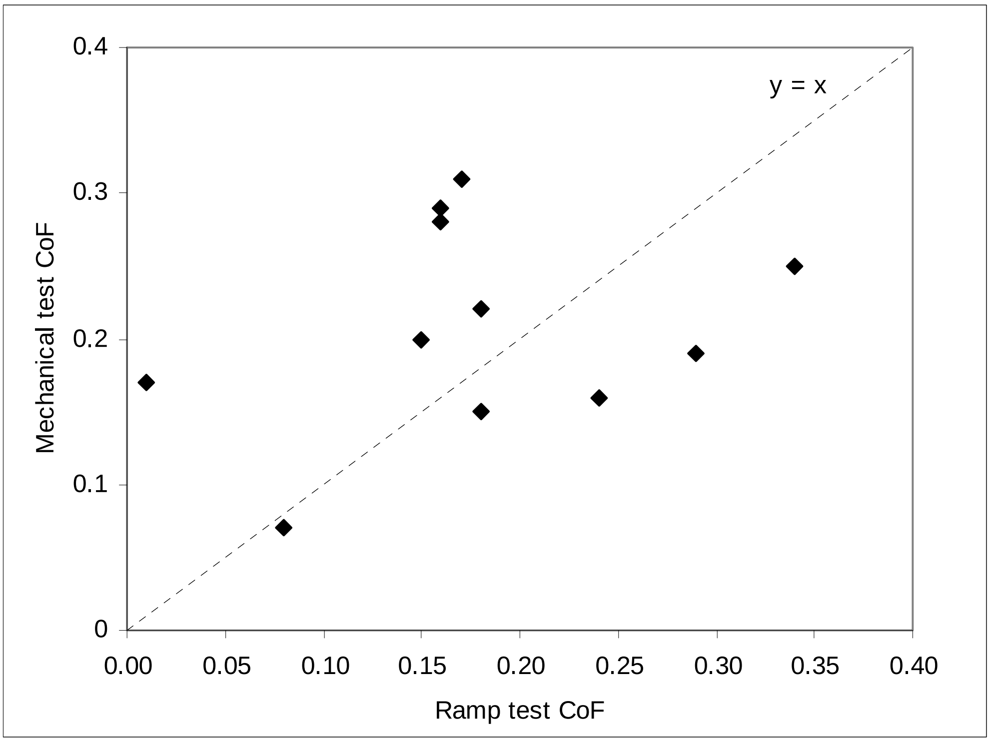

Figure 3.12. CoF with the mechanical test - heel test mode, ceramic tile surface with glycerol, slip speed of 0.5ms^{-1}, vertical force of 500N

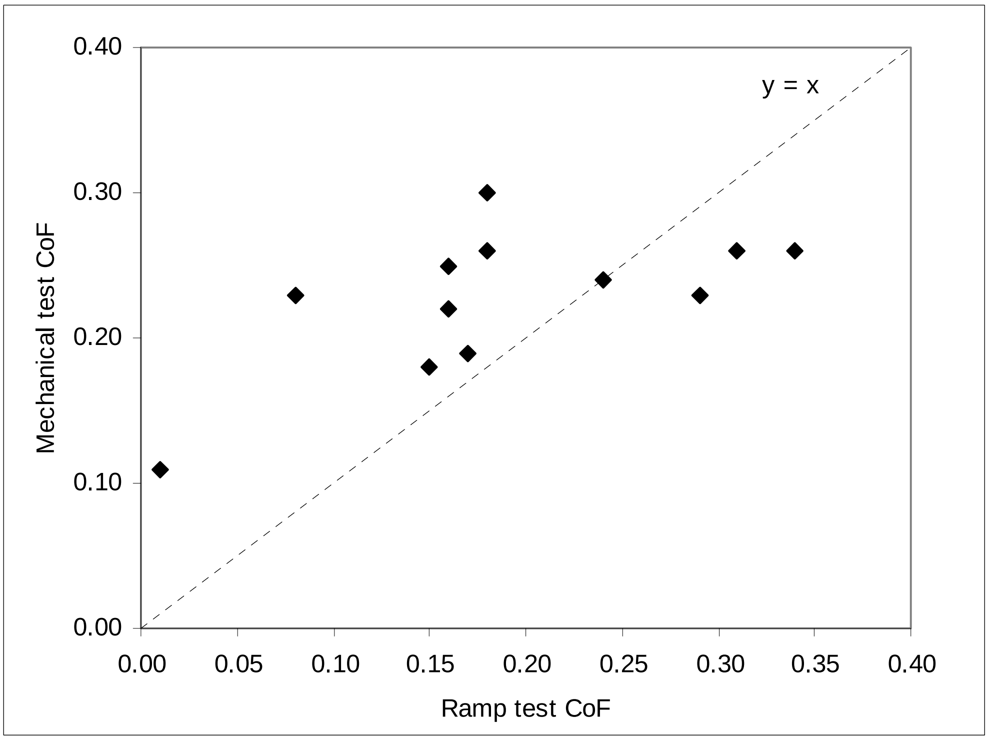

Figure 3.13. CoF with the mechanical test - flat test mode, ceramic tile surface with glycerol, slip speed of 0.5ms^{-1}, vertical force of 500N

3.5 SLIP SPEED OF 0.5MS^{-1}, VERTICAL FORCE OF 450N

The vertical force applied was next reduced by a small amount (50N) to 450N. Measurements were made in the heel test mode on the vitrified ceramic tile surface contaminated with glycerol. This surface and contaminant combination was chosen because the feature identified in Section 3.4 was most pronounced for the combination.

The coefficients of friction with the force reduced to 450N are shown in figure 3.14.

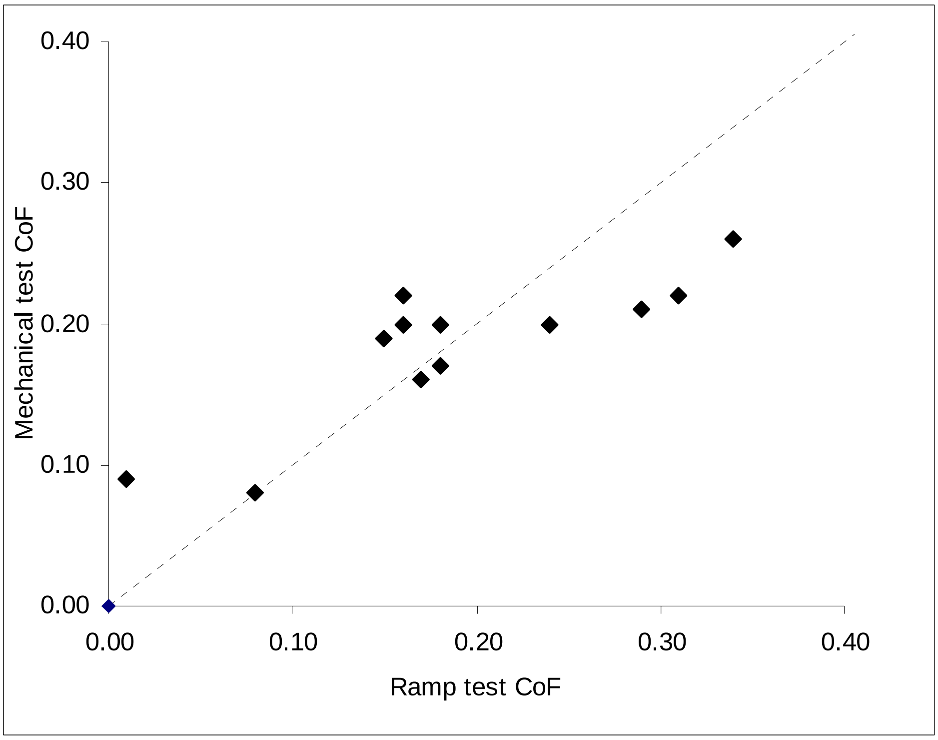

Figure 3.14. CoF with the mechanical test - heel test mode, ceramic tile surface with glycerol, slip speed 0.5ms^{-1}, vertical force of 450N

The results in figure 3.14 were unexpected. The small reduction in the vertical force caused the spread of mechanical test coefficients of friction for the sub-set of footwear identified in the previous section to reduce significantly. At first sight this appeared to be an effect on footwear with a coefficient of friction in the mid range. However on further examination the slight reduction in vertical force had affected the mechanical test coefficient of friction for footwear across the entire range of ramp coefficients. This may be seen by comparing figures 3.12 and 3.14, where the only difference in test conditions is a reduction of the vertical force from 500N to 450N.

It can be seen more easily in figure 3.15. The mechanical test coefficient of friction for each sample for a vertical force of 500N is plotted along with that for 450N, with a vertical line connecting the coefficients for each pair of readings. It is clear from this figure that the small change in vertical force affected footwear across the entire range of ramp coefficient of friction.

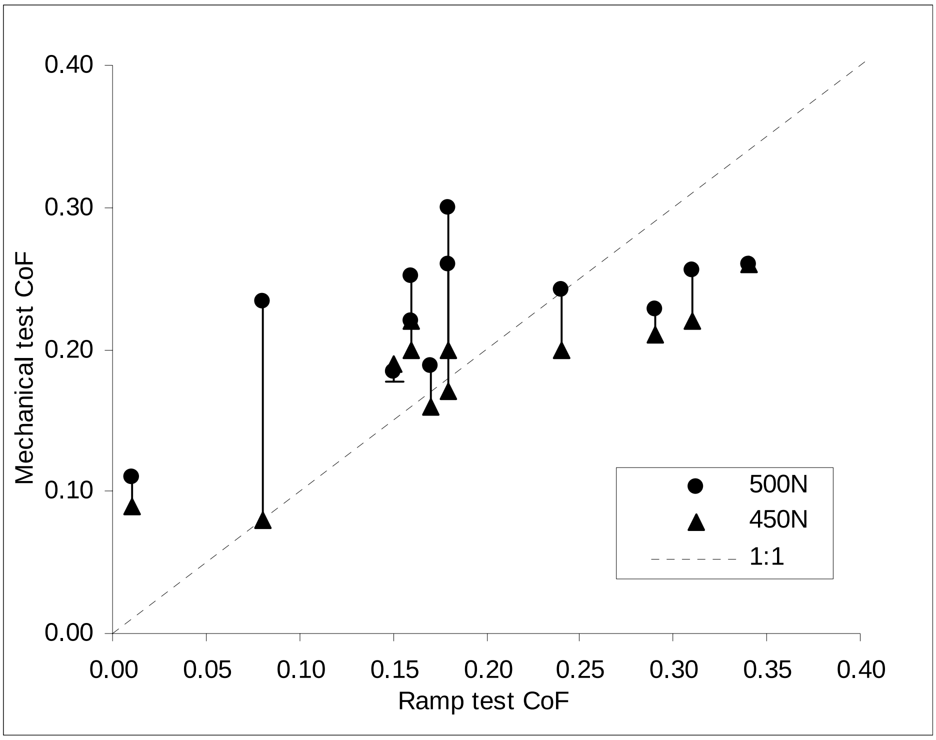

Figure 3.15. CoF with two vertical forces - heel test mode, ceramic tile surface with glycerol, slip speed of 0.5ms^{-1}

3.6 SUMMARY

The results in figures 3.1 to 3.4 do not show good agreement between the mechanical test coefficients of friction and those from the ramp test.

The mechanical test did not differentiate between the footwear in the same way as the ramp test. The results suggest that the mechanical test is not replicating the dynamics of a slip, and only able to partially generate a fluid film between the footwear and the surface. This may be an indication that the constant vertical force and speed of the mechanical test are not representative of the changing values of the parameters of a slip.

The findings in Section 3.5 led to the conclusion that the mechanical test was sensitive to small changes in the vertical force. Furthermore, the degree of change in coefficient of friction as a result of a 50N reduction (or 5kg change in load) varied from footwear sample to footwear sample.

The findings in the previous sections led to the conclusion that the values of the parameters used in the mechanical test could not be optimised to bring the measured coefficients of friction into good agreement with those from the HSL ramp test.

4. REFERENCES

BS EN ISO 13287: 2007 Personal Protective Equipment – Footwear - Test Method for Slip Resistance, British Standards Institute, London.

BS EN ISO 20344: 2004 + A1 2007 Personal Protective Equipment – Test Methods for Footwear, British Standards Institute, London.

BS EN ISO 20345: 2004 +A1 2007 Personal Protective Equipment – Safety Footwear, British Standards Institute, London.

BS EN ISO 20346: 2004 + A1 2007 Personal Protective Equipment – Protective Footwear, British Standards Institute, London.

BS EN ISO 20347: 2004 + A1 2007 Personal Protective Equipment – Occupational Footwear, British Standards Institute, London.

Chambers A., Margerum S., Redfern M. S. and Cham R., (2002/2003), *Kinematics if the Foot During Slips*, Occupational Ergonomics 3, pp225-234.

Darby A., Houlihan R., Hunwin G., Thorpe S., (2012) *In progress. Draft title Safety footwear and accidents* HSE Research Report

Fischer H., Kirchberg S., and Moessner T., (2009), *Biomechanical Gait Analysis for the Extraction of Slip Resistance Test Parameters*, Industrial Health, 47, pp617-625.

Fuller, D.D., 1956, Theory and Practice of Lubrication Engineers, WILEY, New York.

Grönqvist R., Roine J., Järvinen E., and Korhonen E., (1989), *An Apparatus and a Method for Determining the Slip Resistance of Shoes and Floors by Simulation of Human Foot Motions*, Ergonomics , Vol. 2, No. 8, pp979-995.

Grönqvist R., (1999), *Slips*, Biomechanics in Ergonomics, edited by Kumar S., pp 351-375, London, Taylor & Francis.

HSL SOP12 – Standard Operating Procedure – Operation of the DIN Ramp. Issue 2, 2009.

Hunwin G., Ormerod K., and Darby A., (2010) A *Study of the Effect of Modifying the European Standard Mechanical Slip Resistance Test for Footwear*, HSE Research Report: RR801.

Perkins P. J., (1978), *Measurement of Slip Between the Shoe and Ground During Walking*, Walkway Surfaces: Measurement of Slip Resistance, ASTM STP 649, Edited by Anderson C. and Senne J., American Society for Testing and Materials. pp 71-87.

Perkins P. J. and Wilson M. P., (1983), *Slip Resistance Testing of Shoes – New Developments*, Ergonomics, Vol. 26, No. 1, pp73-82.

Proctor, T.D. and Coleman, V., 1988. Slipping, Tripping and Falling Accidents in Great Britain – Present and Future, Journal of Occupational Accidents, 9: 269-285.

Redfern M.S., Cham R., Gielo-Perczak K., Grönqvist R., Hirvonen M., Lanshammar H., Marpett M., Yi-Chung Pai C., and Powers C., (2003), *Biomechanics of Slips*, Measuring Slipperiness, Human Locomotion and Surface Factors, Edited by Chang W. and Courtney K., Taylor & Francis, London, pp37-65.

Strandberg L., and Lanshammar H., (1981), *The Dynamics of Slipping Accidents*, Journal of Occupational Accidents, 3: 153-162.

Thorpe S., Lemon P. and Hawkins M. (2003) *Industrial slip and fall accidents. Can footwear make a difference?* Health and Safety International 2003

Published by the Health and Safety Executive 12/12

Health and Safety
Executive

Optimisation of the mechanical slip resistance test for footwear used in EN ISO 13287:2007

Follow on study

The measurement of the slip resistance of footwear is inherently difficult due to the complexity of the human gait, which leads to changing values of the biomechanical parameters during the walking step. Only some steps result in a slipping heel, which compounds the difficulty in identifying the values of the parameters that need to be simulated. A number of studies have attempted to measure the parameters of walking and/or a slip, in order that realistic values can be incorporated into tests attempting to replicate the slip process.

This report and the work it describes were funded by the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the author alone and do not necessarily reflect HSE policy.

RR951

www.hse.gov.uk