Comparative Performance of the Cambridge Abrasion Machine in Different Laboratories

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Abstract

Motorcycle protective clothing has been well established as an effective means of preventing abrasion injuries to motorcycle riders involved in crashes, yet the performance of this clothing can be variable. The European Standard for motorcycle protective clothing assesses the abrasion resistance quality of motorcycle protective clothing using tightly specified equipment. The absolute time required to abrade a material is reliant on the specifications of the abrasion machine, and it is unknown if measurements taken on machines with different specifications can provide useful information. This study examined the abrasion resistance of materials tested on two different machines built to slightly different specifications. These results confirm machines of different specifications can produce comparable results, and demonstrate capacity to use a non-standard machine to examine comparative performance of materials.

Background

Specifically designed protective clothing has been proven to prevent soft tissue injuries among motorcyclists; however, the performance of this protective clothing in Australia can be variable (de Rome et al., 2011). One International Standard which is designed to assess the performance of motorcycle protective clothing is the European Standard for motorcycle protective clothing, EN13595. EN13595 assesses the ability of materials used in protective clothing to resist the most common types of garment damage: abrasion, burst, cut and tear. While there is a European Standard for motorcycle clothing, there is no Standard in Australia, and garments certified to this Standard are difficult to obtain from motorcycle clothing retail outlets in Australia. While there is an Australian set of guidelines for the construction of motorcycle protective clothing, these are not mandatory and the abrasion guidelines are based on an irrelevant test procedure which applies a very gentle abrasion to the fabric. This tests the normal wear and tear of the material rather than resistance to the level of abrasion that motorcycle clothing would be subjected to when a rider slides across the roadway following a crash. This means that the adequacy of protective clothing available to Australian motorcyclists is unknown and moves are being made to provide information to Australian motorcycle riders on the quality of the clothing being sold.

According to EN13595, abrasion resistance performance must be assessed using a Cambridge abrasion machine and specifications for this machine are contained within the Standard. The Cambridge abrasion machine was a machine that was developed by Woods (1996a) in order to be able to test motorcycle clothing on a Standardised test machine. The Cambridge abrasion machine is a method for assessing abrasion resistance of materials that involves dropping a sample of material onto a moving abrasive belt and timing the length it takes the material to hole, where a hole is any small visible gap opened through the fabric. Woods developed the machine through replicating the damage seen to 32 garments damaged in real-world crashes and during dummy crash tests (Woods, 1996b). Woods manipulated the height that the fabric is dropped, the belt grit, the speed of the abrasive belt, the force at which the material is held onto the abrasive belt and the contact area of the sample on the belt until the damage seen to the clothing in the real-world and

dummy tests was replicated. To determine an appropriate drop height, samples were lowered gently onto the belt or dropped from heights of up to 1.5 m. A drop height of 50 mm was deemed to be appropriate and gave results consistent with the dummy tests. For drop heights greater than 50 mm, those materials that had a low tear strength tore on impact. Belt abrasion grits OP24, OP40, OP60 and OP80 were tested. The OP80 belt could not be kept sufficiently clean while, due to the larger grit size of the particles, the OP24 and OP40 belts gave very short abrasion times, so the OP60 belt was the most appropriate. The force on the sample holder was increased progressively from 3 kg (29.4 N) to 5 kg (49 N) while the abraded area was reduced until damage replicated. The final force was chosen to be 49 N and contact area 1963 mm² as this was the force with which the damage was replicated (Woods, 1996a, 1996b).

We have previously demonstrated that the EN13595 method is a valid way to evaluate the abrasion resistance quality of protective clothing designed for motorcyclists where the time taken for materials to abrade when subjected to the Cambridge method is related to the probability of a rider sustaining soft tissue injury (Meredith et al., 2015). However, the absolute time required to abrade any particular material is reliant on the specifications of the abrasion machine. In this study, we have examined the abrasion resistance of materials tested on two different Cambridge abrasion machines built to slightly different specifications.

Method Overview

Testing was conducted on two different machines that were specifically designed to perform in a similar manner to the Cambridge abrasion machine. Machine 1 is located at Neuroscience Research Australia and was built to conduct experiments examining the abrasion resistance performance of clothing worn by Australian motorcycle riders. This machine differed from the Cambridge abrasion machine specified in EN13595 in that it operated at a 40 N (4.1 kg) compressive load on the sample, rather than the 49 N specified in the standard, due to limitations of the equipment. The sample size diameter was also reduced to maintain the same contact pressure (25 kpa). All other specifications including belt grit were the same as that specified in EN13595. Machine 2 (made by Mesdan LAB, Italy) meets all specifications of the test equipment detailed in EN13595 and was purchased as a Cambridge abrasion machine to test clothing to EN13595. It is located at Deakin University, Australia.

This study involved a two-stage method. In stage 1, reference materials were tested on both machines to establish a scaling factor that could be applied to ensure equivalency of results from the two machines. In stage 2, motorcycle garments worn by riders who had crashed were purchased and tested on the two different abrasion test machines and the scaling factor derived from Stage 1 was applied.

Method – Stage 1

A scaling factor was derived from testing reference material on both machines using the EN13595-2 protocol as described in Stage 2. The reference material is a standard canvas specified in EN13595-2. Two layers of the reference fabric were measured for each test. Six samples of reference material were tested, two along the warp, two along the weft and two at 45 degrees to the warp and weft. Once the average abrasion time for the reference material was obtained for both abrasion machines, the ratio between the two abrasion times was computed. This scaling factor could then be used in Stage 2 to scale the abrasion time results obtained from Machine 1.

Method Stage 2

Sample

The data used for this study was collected during in-depth crash investigation (Brown et al., 2015) . In summary, motorcycle riders who had been involved in motorcycle crashes were recruited from two Sydney hospitals and one regional hospital from August 2012. To qualify for the study, riders had to be at least 16 years of age and had crashed on public roads within the study area. Following recruitment, riders were required to complete a face-to-face interview and the hospital medical records were reviewed. The scene where the crash occurred and the motorcycle ridden at the time of the crash were also inspected for crash evidence. Where possible, clothing was inspected and then collected from riders for testing. Clothing was sometimes unable to be inspected or collected due to the clothing having been thrown out, sent to insurance companies or lack of rider consent. If the clothing was inspected but the rider did not consent for the clothing to be kept and tested, the brand name and model of the clothing was recorded and new clothing items were purchased to the same specifications.

Test methodology

Testing was conducted in line with the test procedures outlined in EN13595. In summary, six circular samples of each material in the garment were retrieved from the garment, each with a diameter of 160 mm and containing all layers of fabric in the clothing at that location. Samples were taken from locations where there was no crash damage and where a large enough sample of material was available. Most of the garments did not follow the clothing template in EN13595, so the samples were not cut according to the template. Instead, the zones with which that material formed part of were recorded. If there was not enough material to obtain six samples, as many samples as possible were obtained. Samples were then attached to the sample holder using a hose clamp. Fibres were oriented either along the warp, weft or at 45 degrees to the warp and weft so that there were two samples tested at each fibre direction. If six samples were unavailable, at least one sample was tested in each direction. If only two samples were available, both were tested at 45 degrees. Once the sample was prepared, the motor was then switched on and the abrasive belt brought up to the appropriate speed (8 m/s). The sample holder with the fabric sample attached was then dropped onto the moving belt and the time taken for the fabric to abrade through was measured. As specified in the Standard procedure, after every 10 tests, a reference fabric was tested to adjust the abrasion time to account for wear of the abrasive belt during testing. In Stage 2, materials from 11 upper garments and 11 lower garments were tested on the two abrasion machines, and the scaling factor calculated in Stage 1 was used to adjust the times obtained from Machine 1. This was achieved by dividing the abrasion time to hole result by the scaling factor. Abrasion times measured from Machine 2 were used without any scaling.

Analysis

Data collected using the procedure that was described above was used to examine the relationship between the scaled time-to hole of the materials tested on Machine 1, and the measured time to hole obtained from Machine 2.

This was achieved using inter-rater reliability statistical procedures. A two-way, mixed, intra-class correlation (ICC) was used to assess the inter-rater reliability between the abrasion times of the garments tested on both machines. The single-measures absolute agreement ICC was analysed and given a rating, with ICC values of less than 0.40 being poor, an ICC between 0.40 and 0.59 being fair, an ICC between 0.6 and 0.74 being good and an ICC for values between 0.75 and 1 being excellent (Hallgren, 2012). Following this, the variance was checked visually using a Bland-Altman plot. The Bland Altman plot is a plot of the difference between the two results obtained from each

method against the mean or average results from the two methods which gives a visual representation of variance.

Results

The scaling factor derived from testing the reference material in Stage 1 was 6.26. This scaling factor was applied and the adjusted average abrasion time results as measured on the two abrasion machines can be seen in Table 1. The garments lasted typically around the 2.5 second range, with the average values being similar between the two machines.

*Table 1. Average abrasion time for the investigated materials as measured on the different abrasion machines*

	Machine 1		Machine 2	
Clothing item	**Abrasion time (sec)**		**Abrasion time (sec)**	
	Mean (sd)	Range	Mean (sd)	Range
Upper garment	2.53 (2.84)	0.14-8.96	2.33 (2.09)	0.1-6.84
Lower garment	2.50 (4.44)	0.14-20.36	2.55 (3.11)	0.5-13.69

The results of the inter-rater reliability test comparing the scaled times from Machine 1 with the actual times obtained from Machine 2 are displayed in Table 2. The inter-rater reliability was excellent, with an ICC of 0.9 (95%CI: 0.828-0.953).

Table 2. Inter-rater reliability of the abrasion results from the two abrasion machines

Variable	ICC	95% CI	p-value
Abrasion time	0.909	0.828-0.953	<0.0005

The one sample t-test found that there was no significance in the difference between the final abrasion times for each material and zero. The Bland-Altman plot is shown in Figure 1. The data on the difference between abrasion times was evenly distributed above and below the mean of the differences between abrasion times with a 95% confidence interval of -2.884 to 2.75 demonstrating good correlation between the two machines. There is one outlier with an average abrasion time of the two results being 17 seconds which reflects the properties of the material used in this garment – in both tests this material took a much longer time to abrade than the other materials.
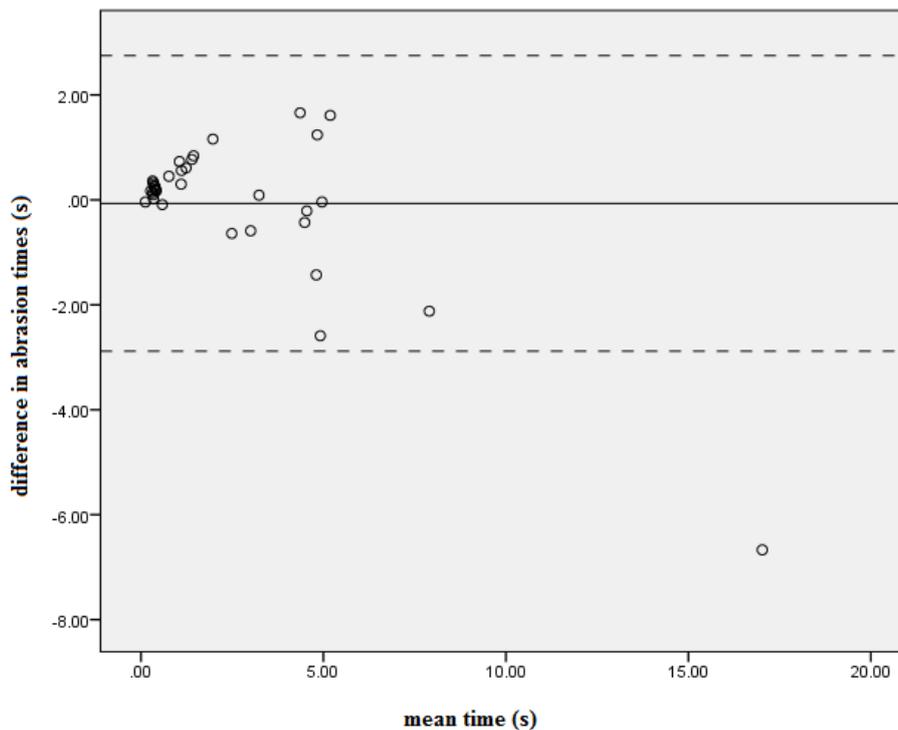
Figure 1. Bland-Altman Plot

Discussion

The key finding of this work was that the correlation between the scaled data on the Machine 1 and Machine 2 was excellent, with an ICC of 0.9. The Bland-Altman diagram supported these findings, with the data being evenly distributed around zero and not significantly different from zero (Figure 1). The average abrasion times for the materials tested in the garments worn by the riders in this study were also similar between the two abrasion machines, with average abrasion times being around 2.5 seconds.

The implication of this finding is that even though a machine may give different times to hole if it is calibrated against a standard machine it can have a calibration factor established for it. This suggests that the abrasion results from Machine 1 were at a set interval from those on Machine 2. This aligns with the observations of Woods in his development of the Cambridge abrasion machine where he reported that the size and pressure of the abrasion head could be scaled to accommodate for measuring samples of different sizes (Woods, 1996a).

Regardless of the differences between the machines, there appears to be inherent variability in the test results within materials tested on the same machine. These small errors may be due to intrinsic problems with the test procedure. The accuracy and sensitivity of the timing mechanism as well as the exact alignment of the fabric, the tautness of the sample on the sample holder and small differences in the abrasive belt may all affect the end result. One way to address this problem may be to add some tolerance levels to the time measurements to allow for these inherent errors.

An additional difference observed between the behaviour of the materials on the different machines was the bursting of some fabrics on Machine 2. This bursting was not observed when the material was subjected to the lower force in Machine 1. The bursting discussed here differs from the bursting identified in the EU Standard as it occurs to the actual material and not the seams of the garment and is characterised by long strips of material in the holing region. This burst damage occurs for some materials as soon as the fabric impacts with the abrasive belt, and the material does not have time to abrade (Blight, Phillips, Hickling, & Hurren, 2015). This lack of bursting in Machine 1 may actually be of benefit for this testing as the garments can be properly ranked in terms of their

abrasion resistance. However, this depends on whether or not the burst behavior of these materials on Machine 2 is consistent with what occurs in the real-world. If this is as an accurate representation of the materials' behavior in crashes, the garments may perform better in the laboratory than they really would in the real-world. Further investigation of the behaviour of materials in the real-world is warranted to determine whether the burst behavior is realistic or not.

Other limitations to keep in mind include the small number of garments tested for abrasion time, and that this investigation only compared two abrasion machines differing on the force with which the sample is abraded and the contact area. Other significant variations between machines may have different effects. Despite this, the high correlation between the abrasion times of the different machines does indicate that a scaling factor can successfully be employed. Additionally, while the exact value of the abrasion times were different on the different machines, the materials were ranked in the same order and the difference between the abrasion times of the two machines were at a set interval. This further indicates the applicability of a scaling factor.

Conclusions

These results confirm that Cambridge abrasion machines of different specifications can produce comparable results when a scaling factor is applied to the abrasion time. Furthermore, the results demonstrate the capacity to use a non-standard specific machine to provide a valid examination of the comparative performance of materials designed for motorcycle use. The importance of this is that it shows that even though a machine may give different times to hole if it is calibrated against a standard machine it can have a calibration factor established for it.

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