

Harpur Hill, Buxton
Derbyshire, SK17 9JN
T: +44 (0)1298 218000
F: +44 (0)1298 218590
W: www.hsl.gov.uk



**Factors affecting the strength of safety harness
and lanyard materials - combinations of effects**

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Project Leader: **Louise Robinson B.Eng. Hons. ProfGrad
IMMM**

Author(s): **Louise Robinson B.Eng. Hons. ProfGrad
IMMM**

Science Group: **Hazard Reduction Group**

CONTENTS

1	INTRODUCTION.....	1
1.1	Background	1
1.2	Material selection.....	1
1.3	Combined effects.....	2
2	METHOD.....	3
2.1	Combined effects exposure	3
2.2	Tensile Testing	5
3	RESULTS	6
3.1	Weathering	6
3.2	Weathering and abrasion.....	6
3.3	Weathering and edge damage	7
3.4	Weathering and ingress of dirt.....	8
3.5	Weathering, abrasion and edge damage.....	9
3.6	Weathering, abrasion, ingress of dirt and edge damage	10
4	DISCUSSION.....	12
4.1	Tensile breaking strength	13
4.2	Elongation to failure	14
4.3	Energy absorbed to failure.....	15
4.4	Summary	17
5	CONCLUSIONS.....	18
6	RECOMMENDATIONS.....	19
7	REFERENCES.....	20
8	APPENDIX.....	21

EXECUTIVE SUMMARY

Objectives

The purpose of this research was to investigate how combinations of several types of damage can affect the breaking strength of webbing used to manufacture safety harnesses and lanyards, used for industrial fall protection whilst working at height. By researching the change in performance of these webbing materials with exposure to damage simulating typical in service conditions, it is hoped that better predictions of the service life of safety harnesses and lanyards will result.

Webbing samples were selected from the same batch as used for the previous study conducted by the Health and Safety Laboratory : R Parkin and L Robinson, *Assessment of the factors that influence the tensile strength of safety harness and lanyard webbings*, HSL/2002/16, 2002. <http://www.hse.gov.uk/research/hsl/hsl02-16.htm>. Webbing types 1, 2, 6, 7 and 8 were used with a new type, 11, introduced. The samples were exposed to all weather conditions for two months, during the months of June and July. After weathering the samples, in batches of three of each type, were then exposed to further damaging effects in the following five combinations:

Weathering and abrasion (WA) – each weathered sample was abraded over one edge of a section of angle iron. One end of the sample was clamped onto an oscillating drum in a specially designed abrasion rig, and was tensioned by clamping a 2.75 kg weight onto the free end. The sample was set up such that the central part was abraded over a length of 150 mm.

Weathering and edge damage (WE) – each weathered sample had a 2 mm edge cut introduced into the centre of its length, using a razor blade.

Weathering and ingress of dirt (WI) – each weathered sample was cycled through a bath of builders' red sand, graded with a 0.6 mm sieve to remove large particles, for 50 cycles using a specially built rig. Each sample was clamped to an oscillating drum such that the central part had a 150 mm long section over which the dirt had been ingressed.

Weathering, abrasion and edge damage (WAE) – each weathered sample was abraded over angle iron for 50 cycles, as described above. A 2 mm edge cut was then introduced into the centre of the abraded area.

Weathering, abrasion, ingress of dirt and edge damage (WAIE) – each weathered sample was abraded over angle iron for 50 cycles and then cycled through the sand bath for 50 cycles, ensuring that the ingress of dirt occurred in the same part of the webbing as the abrasion. A two millimetre edge cut was then introduced into the centre of the abraded and ingressed area.

After the samples had been exposed to these combinations of effects, quasi-static tensile tests were carried out to determine the effects of the exposure on the properties of the webbing materials.

Main Findings

Weathering and ingress of dirt (WI) was found to be the most significant damaging combination in this study, with the combination of weathering, ingress of dirt, abrasion and edge damage found to be the most harmful. The second most damaging combination of effects was that of weathering and ingress of dirt.

The results show that for most of the webbing types, the severity of damage, based on breaking strength and elongation to failure, increases in the following order:

- Weathering and abrasion *least severe*
- Weathering and edge damage
- Weathering, abrasion and edge damage
- Weathering and ingress of dirt
- Weathering, abrasion, ingress of dirt and edge damage *most severe*

The least severe combination of effects was that of weathering and abrasion.

Webbing 11 showed the largest average reduction in strength of 40.9% when exposed to the combined effects of weathering, abrasion, ingress of dirt and edge damage.

Webbing 8 showed the largest average reduction in elongation to failure of 29.5% after exposure to weathering and ingress of dirt.

Webbing 6 showed the largest average reduction in energy absorbed to failure, of 58% after exposure to weathering, abrasion, ingress of dirt and edge damage.

There was no apparent correlation between the failure mode of the webbing samples and the breaking loads obtained.

Recommendations

The results obtained in this study highlight how combinations of relatively small amounts of damage can have a severe effect on the tensile properties of webbings. In a dynamic fall situation, these combinations of effects could have an equally or more severe effect on the dynamic performance of webbings. A study into the effects of combinations of damage on the dynamic performance of the webbings is highly recommended. The dynamic performance of webbings was previously studied by the author: L Robinson, *Development of a technique to measure the dynamic loading of safety harness and lanyard webbing*, HSL/2006/37, 2006. http://www.hse.gov.uk/research/hsl_pdf/2006/hsl0637.pdf.

The combination of weathering, ingress of dirt and edge damage was not investigated in the current programme. The effects of this damage on the tensile properties of the webbing are expected to be severe and similar to weathering, abrasion, ingress of dirt and edge damage. There may be some value in conducting these tests to explore this combination.

During weathering it is known that sunlight has a strong effect on the webbing properties, but not to what extent wetting and drying or abrasion effects have on webbings. Exposing webbings to wetting and drying cycles may prove a valuable condition to investigate.

A study into the effects of melting damage and its interaction with other damaging effects is also recommended. In previous examinations of harnesses removed from service the author has observed many occurrences of melting damage. Pin-point sized melting damage typical of that seen arising from sparks (from, for example welding spatter, grinding and cutting), as well as larger, more localised damage would be studied initially, including the effects of position of the melting damage (middle or edge) on the tensile properties of webbing. This study could then be expanded to include the combined effects of melting and abrasion, melting and edge damage etc. It is possible that areas of melting damage may act as easy paths for failures to propagate under tensile loads and, combined with effects such as weathering and/or abrasion and edge

damage, could have a strongly deleterious affect on the tensile and dynamic properties of webbings.

1 INTRODUCTION

1.1 BACKGROUND

The purpose of this research was to investigate how combinations of several types of damage on safety harness and lanyard webbing can affect their breaking strengths. By researching the change in performance of these webbing materials with exposure to damage simulating typical in service conditions, it is hoped that better predictions of the lifetimes of safety harnesses and lanyards will result.

Currently BS EN 354: 2002 “Personal protective equipment against falls from height – Lanyards” states that all textile lanyards must withstand a static force of at least 22 kN. This minimum strength must be achieved by all new products on the market, however after those products have been in service, various damaging effects to which they are exposed can reduce the strength of the webbing material from which they are manufactured. This can mean that lanyards, having met the requirements of BS EN 354:2002 when new, may no longer meet the requirements after only a short time in service.

Previous research commissioned by the Health and Safety Executive, and conducted by Health and Safety Laboratory [Parkin and Robinson, 2002, <http://www.hse.gov.uk/research/hsl/hsl02-16.htm>], studied how different types of damage affected the tensile properties of webbings. The webbing samples in that study were exposed to single damaging effects and were then tested to determine their tensile breaking strength, elongation to failure and energy absorbed to failure. In service, a webbing lanyard or safety harness would be more likely to be exposed to several damaging factors, rather than isolated ones.

I was asked by Mr Martin Holden, formerly of Health and Safety Executive (HSE) Construction Division Technology Unit, to investigate the effect on webbing samples of exposing them to different combinations of damaging effects. This programme of research was set up to examine combinations of weathering, known to cause significant losses in strength, with other damaging factors, namely ingress of dirt, edge damage and abrasion.

Research into webbing performance contributes towards HSE’s commitment to reduce fatal and major injuries resulting from falls from height under the FIT3 programme (Fit for Work, Fit for Life, Fit for Tomorrow) [<http://www.hse.gov.uk/aboutus/plans/hscplans/0506/fitfor.htm>].

1.2 MATERIAL SELECTION

The webbing materials under investigation for this test programme were the same selection as used in the previous study by HSL [Parkin and Robinson, 2002], but with four types of webbing removed. Webbing 3 had been removed in the previous study because it failed to meet the minimum tensile strength required by BS EN 354 (1993) of 22 kN when new, and webbings 9 and 10 were removed, because they have been withdrawn by the manufacturer as a result of the findings of that study. Two further webbing types had been discontinued by another manufacturer for commercial reasons; webbing 5 was discontinued in the particular colour investigated previously, so was substituted with a different coloured webbing by the same manufacturer, to increase the sample group. Webbing 4 was also discontinued, but a number of samples remained from the previous programme in sufficient quantities for the abrasion and

dynamic testing programmes. Six webbing types were selected for testing, five from the original batch, numbers 1, 2, 6, 7, 8 and one new type, designated number 11 (a new version of type 4 from the original batch). The webbings were of varying widths and thicknesses, however exact details cannot be given to protect the manufacturers' anonymity. For each test condition three samples of each webbing type were exposed, resulting a total of 90 samples.

Throughout this report the webbings will be referred to by the numbers which were designated to them in the previous research in order to provide ease of reference to that work.

1.3 COMBINED EFFECTS

In the previous study [Parkin and Robinson, 2002] weathering damage was found to be quite severe, as it combined exposure to natural sunlight (including ultraviolet exposure), wetting and drying cycles, and exposure to wind causing the samples to rub against each other, on the edges as well as the faces.

The effect of edge damage was also severe, with the previous study finding that 1mm, 2 mm and 4 mm edge cuts caused severe losses of strength. Edge damage of 4 mm was found to cause up to a 40 % reduction in strength. For this reason, an intermediate level of damage was chosen (2 mm).

Ingress of dirt was a very severe test, producing large losses of strength due to internal abrasion by dirt particles. The previous study had exposed samples to 50, 1000 and 5000 cycles. Large losses in strength occurred initially after only 50 cycles, with increased exposure having a less significant effect. For this reason 50 cycles of damage was chosen for this test programme.

Abrasion over angle iron has been studied in a research programme, conducted by HSL, running concurrently with this programme [Robinson, 2006]. This research studied the effects of surface abrasion on the strength of webbing materials. Abrasion over angle iron was found to produce losses in strength similar to those observed for ingress of dirt. With the most severe damage produced over the first 50 cycles, with subsequent cycles having slightly less effect. For this reason, 50 cycles exposure was chosen for this test programme.

The test programme carried out consisted of three sample groups which were exposed to two types of damage, one sample group exposed to three types of damage, and one sample group exposed to all four types of damage. This allowed not only the interaction of weathering and a single other effect to be examined, but also allowed a study of the interaction of weathering with two other effects, and weathering with three other effects.

Three possible outcomes of the research were considered: the effects could have been additive, so simply adding more effects causes more damage; one effect could have been so severe it would dominate over the other effects; and the effects could have been synergistic, with their combination causing a very much greater than expected loss of strength.

2 METHOD

2.1 COMBINED EFFECTS EXPOSURE

Eighteen one metre long samples were cut from each of the webbing types, resulting in 90 samples, and sealed using a flame at the cut ends to prevent fraying. Holes were cut at either end of the webbing to form attachment points for weathering, and these were also sealed using a flame. The samples were attached using plastic ties to a freely rotating weathering frame (Figure 1).



Figure 1. Exposure to all weather conditions on a freely rotating frame

The samples were exposed to all weather conditions in a rural environment for two months, during the months of June and July 2004. The samples were turned periodically to ensure that both sides received, as near as possible, similar exposure to sunlight.

After weathering the samples were divided into groups containing three samples of each type of webbing then exposed to further damaging effects in the following five combinations:

Weathering and abrasion (WA) – each weathered sample was abraded over one edge of section of mild steel angle iron measuring 50mm x 50 mm x 15 mm, for 50 cycles using a specially built rig, Figure 2. One end of the sample was clamped onto an oscillating drum, and was tensioned by clamping a 2.75 kg weight onto the free end. The samples were set up such that the abrasion occurred in the centre, with the abraded part of each sample measuring 150 mm in length.

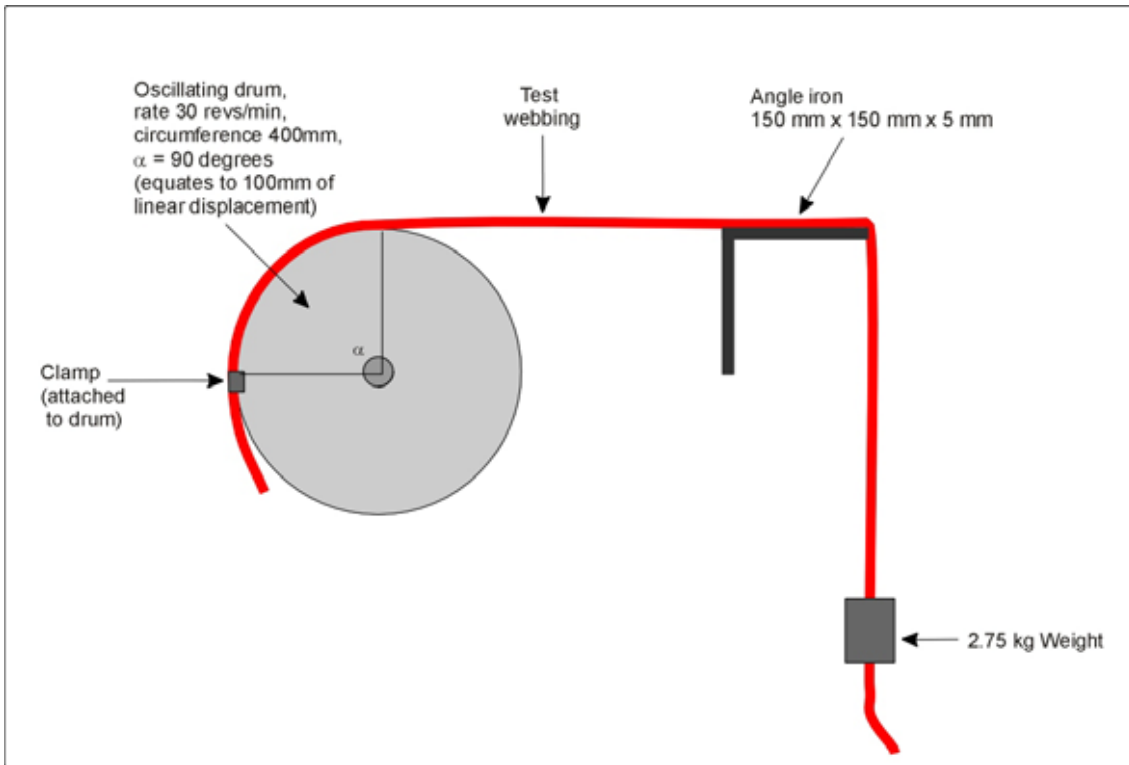


Figure 2. Abrasion rig with angle iron abradant

Weathering and edge damage (WE) – each weathered sample had a 2 mm edge cut introduced into the centre of its length, using a razor blade, Figure 3.

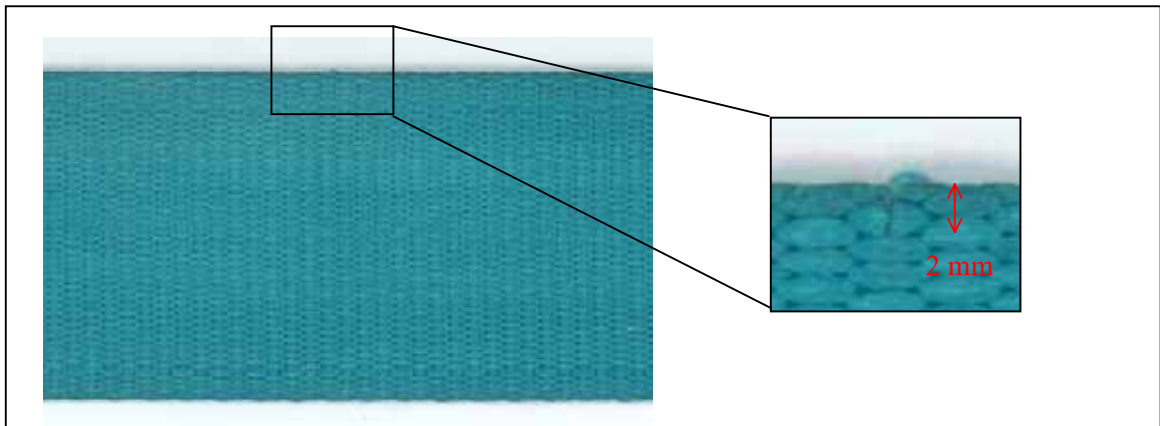


Figure 3. 2 mm edge damage in webbing (colour digitally changed to anonymise product)

Weathering and ingress of dirt (WI) – each weathered sample was cycled through a bath of builders' red sand for 50 cycles using a specially built rig (Figure 4). One end of the sample was clamped to an oscillating drum, and the other end clamped to a piece of sacrificial webbing for tensioning, which passed underneath the sand bath and itself was attached to the oscillating

drum. Each sample was set up so that it had a 150 mm long section in the centre of its length over which the dirt had been ingressed.

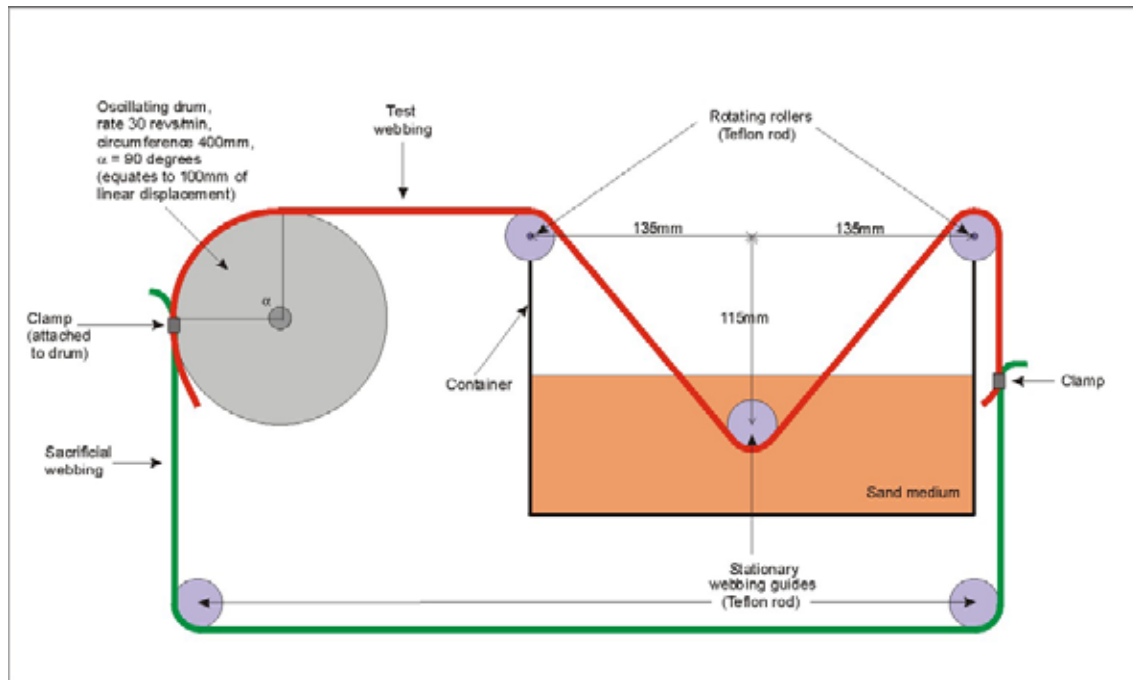


Figure 4. Schematic of the ingress of dirt rig

Weathering, abrasion and edge damage (WAE) – each weathered sample was abraded over angle iron for 50 cycles, as described above. A 2 mm edge cut was then introduced into the centre of the abraded area, using a razor blade.

Weathering, abrasion, ingress of dirt and edge damage (WAIE) – each weathered sample was abraded over angle iron for 50 cycles and then cycled through a sand bath for 50 cycles, ensuring that the ingress of dirt occurred in the same central part of the webbing as the abrasion. A 2 mm edge cut was then introduced using a razor blade, in the centre of the abraded and ingressed area.

2.2 TENSILE TESTING

The weathered and damaged samples were pulled to failure using a Mayes 500kN test machine, calibrated to an accuracy of 1%, controlled with a Rubicon controller, in order to determine their tensile breaking strength. The samples were tested at a constant rate of extension of 50 mm/minute. The loads were measured using a 100 kN load cell, and the results output in the form of load against stroke. From this data the tensile breaking strength and the elongation to failure for each sample were determined, and the energy absorbed to failure calculated.

3 RESULTS

3.1 WEATHERING

After weathering the samples showed some discolouration, a brief summary of which is given below. In order to protect the manufacturers' anonymity the webbings colours are not described and photographs of the samples are not included.

Webbings 1, 6, and 8 showed no discernible fading to the main body of the webbing, and only some slight fading to the contrast stitching in the case of Webbing 1. Webbings 2 and 7, which were similar colours showed fading of colour. Webbing 11 showed slight fading.

During the exposure to all weather conditions the samples were outdoors and unprotected in a rural environment. Although this exposure was intended to comprise solely of weather conditions, another variable was introduced inadvertently, by nature, in the form of bird faeces. This, however, had no significant effect on the performance of the samples affected.

3.2 WEATHERING AND ABRASION (WA)

The samples exposed to weathering and abrasion showed the weathering effects, as described above, and had a small amount of broken surface fibres visible to the naked eye after WA.

The tensile failures observed all occurred in the abraded area. In webbings 1, 6 and 7 the failures propagated perpendicular to the load, and in the other types propagated diagonally across the width of the sample.

The tensile test results are listed in Table 1, below. The energy absorbed to failure was determined by calculation of the area under the load against elongation graphs plotted from the data collected.

Table 6 shows the results for the webbings tested in the 'as received' undamaged state.

Webbing designated number	Test number	Maximum load, kN	Elongation, m	Energy absorbed, kJ
1	1	25.54	0.1122	1.382
	2	25.03	<u>0.1072</u>	1.365
	3	<u>24.54</u>	0.1088	<u>1.280</u>
	Average	25.04	0.1094	1.342
2	1	35.90	0.2404	2.634
	2	36.54	0.2142	<u>2.100</u>
	3	<u>35.46</u>	<u>0.2068</u>	2.155
	Average	35.96	0.2205	2.499
6	1	36.89	0.1517	2.840
	2	<u>32.79</u>	0.1723	<u>2.083</u>
	3	34.60	<u>0.1386</u>	2.440
	Average	34.76	0.1542	2.454
7	1	24.62	0.1294	1.290
	2	26.65	<u>0.1226</u>	<u>1.257</u>
	3	<u>24.13</u>	-	-
	Average	25.13	0.1261	1.274
8	1	23.03	0.2062	1.622
	2	<u>20.70</u>	0.1929	1.590
	3	22.20	<u>0.1686</u>	<u>1.357</u>
	Average	21.98	0.1892	1.523
11	1	34.36	0.1199	1.813
	2	33.00	0.1188	1.763
	3	<u>31.21</u>	<u>0.1116</u>	<u>1.544</u>
	Average	32.85	0.1168	1.707

Table 1. Tensile test results after exposure to weathering and abrasion

The data in bold numerals shows the average results obtained. The data in blue numerals and underlined shows the lowest result obtained. Dashes are present for test 3, webbing 2 as the data was lost due to a computer error during collection.

3.3 WEATHERING AND EDGE DAMAGE (WE)

The samples exposed to weathering and edge damage showed the weathering effects as described above and also had a two millimetre cut in the edge of the webbing, near the centre of the sample length.

All of the tensile failures propagated from the edge cut, with failures predominantly following a path across the webbing perpendicular to the applied load. Webbing 2, however failed in three modes, firstly by tearing of a strip from the cut edge along the sample length, parallel to the applied load, then diagonally across the webbing to the centre and finally tearing from the centre to the opposite edge perpendicular to the applied load.

The tensile test results are listed in Table 2, below.

Webbing designated number	Test number	Maximum load, kN	Elongation, m	Energy absorbed, kJ
1	1	24.26	0.1001	1.167
	2	21.69	0.0981	1.052
	3	<u>21.15</u>	<u>0.0923</u>	<u>0.966</u>
	Average	22.37	0.0968	1.062
2	1	35.67	0.1936	2.638
	2	<u>30.82</u>	0.2101	2.377
	3	33.36	<u>0.1866</u>	<u>2.057</u>
	Average	33.28	0.1968	2.357
6	1	33.90	0.1552	2.385
	2	<u>27.07</u>	0.1328	<u>1.743</u>
	3	29.33	<u>0.1268</u>	1.846
	Average	30.10	0.1382	1.992
7	1	27.68	<u>0.1201</u>	1.421
	2	<u>24.90</u>	0.1308	1.464
	3	26.06	0.1240	<u>1.311</u>
	Average	26.21	0.1249	1.398
8	1	22.61	0.2026	1.514
	2	<u>15.45</u>	<u>0.1736</u>	<u>0.970</u>
	3	20.49	0.1886	1.267
	Average	19.51	0.1883	1.250
11	1	29.90	0.1062	1.437
	2	<u>27.21</u>	0.1073	1.311
	3	27.47	<u>0.0998</u>	<u>1.249</u>
	Average	28.91	0.1044	1.332

Table 2. Tensile test results after exposure to weathering and edge damage

The data in bold numerals shows the average results obtained. The data in blue numerals and underlined shows the lowest result obtained.

3.4 WEATHERING AND INGRESS OF DIRT (WI)

Following exposure to this damage, the webbing samples showed the weathering effects as described above, and the central 150 mm length was dirty due to ingress of red sand and dust. The webbing was stiffer in the ingressed area and showed some abrasion and broken surface fibres.

The tensile failures all occurred in the ingressed area. There were a mixture of both diagonal failures and failures perpendicular to the applied load. Only webbings 8 and 11 consistently broke diagonally across the webbings.

The tensile test results are listed in Table 3, below.

Webbing designated number	Test number	Maximum load, kN	Elongation, m	Energy absorbed, kJ
1	1	21.91	0.0924	0.973
	2	20.86	0.0933	0.978
	3	<u>20.86</u>	<u>0.0924</u>	<u>0.926</u>
	Average	21.21	0.0927	0.959
2	1	30.06	0.1826	1.818
	2	<u>29.53</u>	0.1778	1.801
	3	29.88	<u>0.1745</u>	<u>1.778</u>
	Average	29.82	0.1783	1.779
6	1	29.43	0.1370	1.843
	2	<u>29.32</u>	<u>0.1305</u>	<u>1.795</u>
	3	29.79	0.1379	1.923
	Average	29.51	0.1351	1.854
7	1	23.74	0.1161	1.211
	2	<u>23.00</u>	<u>0.0994</u>	<u>1.059</u>
	3	23.94	0.1831	1.857
	Average	23.56	0.1328	1.376
8	1	17.67	0.1487	0.937
	2	<u>16.98</u>	0.1472	<u>0.917</u>
	3	18.12	<u>0.1105</u>	1.101
	Average	17.59	0.1354	0.985
11	1	22.84	<u>0.0915</u>	<u>0.956</u>
	2	<u>23.27</u>	0.1105	1.101
	3	23.73	0.1090	1.093
	Average	23.28	0.1037	1.050

Table 3. Tensile test results after weathering and ingress of dirt

The data in bold numerals shows the average results obtained. The data in blue numerals and underlined shows the lowest result obtained.

3.5 WEATHERING, ABRASION AND EDGE DAMAGE (WAE)

Following exposure to this damage, the webbing samples showed the visual effects as described above, for weathering and abrasion, and had a 2 mm edge cut in the centre of the abraded area.

The tensile failures all occurred in the abraded area and originated at the edge cut. There were a mixture of both diagonal failures and failures perpendicular to the applied load. Webbing 2 however showed one failure which travelled diagonally across the webbing and propagated down the centre of the weave, eventually failing diagonally.

The tensile test results are listed in Table 4, below.

Webbing designated number	Test number	Maximum load, kN	Elongation, m	Energy absorbed, kJ
1	1	23.10	0.1011	1.121
	2	<u>20.79</u>	<u>0.0946</u>	<u>0.932</u>
	3	22.90	0.0977	1.080
	Average	22.26	0.0978	1.044
2	1	<u>23.69</u>	0.1949	<u>1.790</u>
	2	33.66	0.1962	2.311
	3	30.94	<u>0.1938</u>	2.270
	Average	29.43	0.1950	2.123
6	1	30.01	0.1418	1.943
	2	<u>21.04</u>	<u>0.1134</u>	<u>1.251</u>
	3	22.85	0.1201	1.451
	Average	24.63	0.1251	1.548
7	1	26.19	<u>0.1168</u>	<u>1.179</u>
	2	<u>22.96</u>	0.1284	1.402
	3	23.13	0.1211	1.237
	Average	24.09	0.1221	1.273
8	1	19.12	0.1879	1.201
	2	<u>17.41</u>	<u>0.1793</u>	<u>1.100</u>
	3	23.21	0.2071	2.266
	Average	19.91	0.1914	1.522
11	1	27.03	0.1098	1.384
	2	<u>26.69</u>	0.1022	<u>1.212</u>
	3	28.00	<u>0.0973</u>	1.302
	Average	27.24	0.1031	0.943

Table 4. Tensile test results after weathering, abrasion and edge damage

The data in bold numerals shows the average results obtained. The data in blue numerals and underlined shows the lowest result obtained.

3.6 WEATHERING, ABRASION, INGRESS OF DIRT AND EDGE DAMAGE (WAIE)

Following exposure to this damage, the webbing samples showed the visual effects as described above, for weathering and abrasion, but had more severe abrasion due to the ingress of dirt exposure. The abraded area was very dirty due to the ingressed sand, had reduced flexibility in this area and had a 2 mm edge cut in the centre.

The tensile failures all occurred in the abraded and ingressed area and originated at the edge cut. Webbing 1, 6 and 7 showed a mixture of both diagonal failures and failures perpendicular to the applied load. Webbing 8 and 11 showed diagonal failures. Webbing 2, however, showed V-shaped failures in two of the three samples tested.

The tensile test results are listed in Table 5, below.

Webbing designated number	Test number	Maximum load, kN	Elongation, m	Energy absorbed, kJ
1	1	21.53	0.0950	1.013
	2	20.79	0.0978	0.921
	3	<u>19.32</u>	<u>0.0869</u>	<u>0.803</u>
	Average	20.55	0.0932	0.912
2	1	27.10	0.1900	1.736
	2	<u>25.79</u>	0.1765	<u>1.634</u>
	3	29.91	<u>0.1764</u>	1.763
	Average	27.60	0.1809	1.378
6	1	<u>22.82</u>	0.1216	<u>1.371</u>
	2	26.21	<u>0.1153</u>	1.420
	3	24.74	0.1197	1.439
	Average	24.59	0.1188	1.410
7	1	23.47	0.1249	1.201
	2	<u>20.90</u>	<u>0.1039</u>	<u>0.846</u>
	3	22.74	0.1091	1.035
	Average	22.37	0.1126	1.028
8	1	18.78	0.1708	1.046
	2	16.42	<u>0.1673</u>	<u>0.920</u>
	3	<u>15.48</u>	0.1712	0.930
	Average	16.89	0.1698	0.965
11	1	<u>21.17</u>	<u>0.0869</u>	<u>0.797</u>
	2	22.31	0.0958	0.916
	3	23.51	0.1067	1.116
	Average	22.33	0.9431	0.943

Table 5. Tensile test results after weathering, abrasion, ingress of dirt and edge damage

The data in bold numerals shows the average results obtained. The data in blue numerals and underlined shows the lowest result obtained.

4 DISCUSSION

Table 6 shows the results previously obtained for the ‘as received’ samples [Parkin and Robinson 2002], with the addition of new results for webbing 11, which was not part of that study. Samples from these batches which had been in storage in a cool, dark place, were tested and the results found to be in good agreement with those tabulated below, and so it was deemed unnecessary to repeat the full range of tests on the ‘as stored’ material. These results are used for comparison to show how the combinations of effects affect the tensile properties of the webbing types.

Webbing, designated number	Test number	Maximum load, kN	Elongation, m	Energy absorbed, kJ
1	1	28.63	0.1238	1.747
	2	29.43	0.1337	1.836
	3	29.75	0.1296	1.897
	Average	29.27	0.1290	1.827
2	1	40.47	0.1850	3.010
	2	40.92	0.2021	3.077
	3	40.23	0.1915	2.983
	Average	40.54	0.1929	3.023
6	1	40.54	0.1650	3.185
	2	40.89	0.1801	3.413
	3	40.73	0.1870	3.429
	Average	40.72	0.1770	3.351
7	1	34.25	0.1501	2.181
	2	34.67	0.1456	2.143
	3	34.65	0.1486	2.191
	Average	34.52	0.1481	2.172
8	1	28.93	0.1936	2.133
	2	28.62	0.1935	2.070
	3	28.46	0.1890	2.043
	Average	28.67	0.1920	2.082
11	1	37.80	0.1262	2.252
	2	35.76	0.1206	1.889
	3	37.78	0.1241	2.084
	Average	37.11	0.1236	2.075

Table 6. Tensile test results of ‘as received’ webbing

Tables 7, 8 and 9 show the average results of tensile testing of the webbing types after exposure to all combinations of effects. The ‘No damage’ column shows the tensile breaking strength of the webbing types in the ‘as received’ condition.

The results from Tables 7, 8 and 9 are displayed in graphical form in Appendix A and are referred to as Figures A1, A2 and A3. Figures A4, A5 and A6 show the average percentage reduction in breaking strength, elongation to failure and energy absorbed to failure respectively, for each of the webbing types, in order of increasing damaging combinations.

4.1 TENSILE BREAKING STRENGTH

Table 7 and Figure A1 summarise the effect of the different combinations of damage on the breaking strength of the webbing materials. Figure A1 has been plotted to show, reading left to right, increasing damage combinations.

	No damage	Weathering and abrasion (WA)	Weathering and edge damage (WE)	Weathering and ingress of dirt (WI)	Weathering, abrasion and edge damage (WAIE)	Weathering, abrasion, ingress of dirt and edge damage (WAIE)
Webbing 1	29.27	25.04	22.37	21.21	22.26	20.55
Webbing 2	40.54	35.96	33.28	29.82	29.43	27.60
Webbing 6	40.72	34.76	30.10	29.51	24.63	24.59
Webbing 7	34.52	25.13	26.21	23.56	24.09	22.37
Webbing 8	28.67	21.98	19.51	17.59	19.91	17.60
Webbing 11	37.11	32.85	28.19	23.28	27.24	22.32

Table 7. Average breaking strength, kN, after exposure to combinations of effects

The results show that the combination of weathering and abrasion has the least reduction in breaking strength, with all but webbing type 8 performing better than the BS EN 354:2002 requirement to meet a minimum breaking strength of 22 kN. Exposure to the combined effects of weathering, abrasion, ingress of dirt and edge damage (WAIE) showed the largest reduction in breaking strength for all webbing types, with two of the six webbing types, numbers 1 and 8, falling below the 22 kN minimum breaking strength. Weathering and ingress of dirt (WI) caused the second most severe reduction in breaking strength for all but two of the webbing types, these being types 2 and 6.

Webbing type 2 performed better than the other webbings tested, with breaking strengths always above 22 kN for each combination of damage. Webbing type 8 performed worse than the other samples, with all combinations of damage resulting in breaking strengths below 22 kN.

Webbings 2, 6, 7 and 11 all performed better than the 22 kN minimum requirement throughout the test programme. Webbings 7 and 11 only just performed better than this requirement after exposure to WAIE.

Figure A4 shows the average percentage reduction in breaking strength for each combination of damage. Again, the combinations of damage have been plotted to show, reading left to right, increasing damage. From this chart weathering abrasion can be seen to cause the least percentage reduction in strength, with the bulk of samples losing approximately 15% of their breaking strength. The combined effects of weathering, abrasion, ingress of dirt and edge damage caused the largest loss of strength, with samples losing between 29% and 41% of their original breaking strength.

Webbing 11 showed the largest reduction in strength of 40.9% when exposed to the combined effects of weathering, abrasion, ingress of dirt and edge damage. However, it also showed the smallest reduction in strength of 10.7 % after exposure to weathering and abrasion.

Webbing 6 showed a very large loss of strength after exposure to weathering, abrasion and edge damage, which did not follow the general trend exhibited by the other webbing types. This webbing showed slightly better performance when exposed to WAIE, which would not be expected to be the case. This may be due to inconsistencies arising from ingress of dirt exposure, as although the sand was sieved to remove the largest particles, it still contains a variety of grain sizes. Each webbing sample is likely to be exposed to a broadly similar distribution of particles, but the individual samples may experience differing exposures due to settling of the sand during the cycles. For this webbing the order of severity of damaging effects was: WA, WE, WI, WAIE, WAE.

4.2 ELONGATION TO FAILURE

Table 8 and Figure A2 summarise the effect of the different combinations of damage on the elongation to failure. Figure A2 has been plotted using the same x-axis (increasing severity of damage) as Figure A1 for ease of comparison, however it can be seen that not all of the webbings continue to follow the trend shown in Figure A1.

	No damage	Weathering and abrasion (WA)	Weathering and edge damage (WE)	Weathering and ingress of dirt (WI)	Weathering, abrasion and edge damage (WAE)	Weathering, abrasion, ingress of dirt and edge damage (WAIE)
Webbing 1	0.13	0.11	0.10	0.09	0.10	0.09
Webbing 2	0.19	0.22	0.20	0.18	0.20	0.18
Webbing 6	0.18	0.15	0.14	0.14	0.13	0.12
Webbing 7	0.15	0.13	0.13	0.13	0.12	0.11
Webbing 8	0.19	0.19	0.19	0.14	0.19	0.17
Webbing 11	0.12	0.12	0.10	0.11	0.10	0.09

Table 8. Average elongation at failure, metres, after exposure to combinations of effects

Webbings 8 and 11 showed the lowest overall elongation at failure after exposure to weathering and ingress of dirt. Webbing 1 had the same elongation to failure after exposure to weathering and ingress of dirt as after exposure to weathering, abrasion, ingress of dirt and edge damage. Webbings 1, 2 and 8 show the largest reduction in elongation after exposure to weathering and ingress of dirt. For webbing 8 this effect is very marked. Webbing 8 also shows weathering, abrasion and edge (WAE) damage as the least damaging combination of effects. Clearly, this

cannot be the case since the combination of WAE should at least be equal to either WA or WE. This result can only be explained by either inconsistent weathering, weave properties or natural variations in the abradant.

Webbings 6, 7 and 11 show lower elongation to failure after weathering abrasion and edge damage than weathering and ingress of dirt. For these webbings the order of severity of damaging effects would be WA, WE, WI, WAE and WAIE.

Given the number of variables in the test programme and the fact that only three samples were used for each webbing type, per combination of damage, it is not surprising that variations in the order of severity of damage are found. However, the overall downwards trend is still maintained, and is the most important finding.

Webbing 8 showed the largest reduction in elongation to failure of 29.5 % after exposure to weathering and ingress of dirt.

Webbing 2 shows an increase in elongation to failure after exposure to WA, WE and WAE. This may be due to the damage sustained affecting the failure mechanism, allowing more unravelling of the fibre bundles to occur.

4.3 ENERGY ABSORBED TO FAILURE

Table 9 and Figure A3 summarise the effect of the different combinations of damage on the energy absorbed to failure of the webbing materials. Again Figure A3 been plotted on the same x-axis as Figure A1 for ease of comparison, but once again, as with Figure A2, some of the webbings are not continuing to follow the trend seen in Figure A1.

	No damage	Weathering and abrasion	Weathering and edge damage	Weathering and ingress of dirt	Weathering, abrasion and edge damage	Weathering, abrasion, ingress of dirt and edge damage
Webbing 1	1.84	1.34	1.06	0.96	1.04	0.91
Webbing 2	3.02	2.50	2.36	1.78	2.12	1.38
Webbing 6	3.35	2.45	1.99	1.85	1.55	1.41
Webbing 7	2.17	1.27	1.40	1.38	1.27	1.03
Webbing 8	2.08	1.52	1.25	0.98	1.52	0.97
Webbing 11	2.08	1.71	1.33	1.05	0.943	0.94

Table 9. Average energy absorbed to failure, kJ, for each combination of effects

These results show that webbings 1 and 2 fit the trend shown in the breaking load data, absorbing less energy to failure after exposure to WI than after exposure to both WE and WAE..

Webbing 7 almost fits the trend, but shows no difference in energy absorption after exposure to WA, and WI. Webbing 11 also almost fit the trend, but showed no difference in energy absorption after exposure to WAE and WAIE.

Again, the number of variables in the test programme, coupled with the small number of tests have given rise to these slight differences in energy absorption between the webbing types, however the overall downwards trend still remains.

Energetically, exposure to weathering and ingress of dirt is less significant than exposure to weathering and edge damage and weathering, abrasion and edge damage.

Webbing 6 showed the largest reduction in energy absorbed to failure, of 58% after exposure to WAIE.

4.4 SUMMARY

The results arising from the programme of testing show that for most of the webbing types, the severity of damage, based on breaking strength, increases in the following order:

- Weathering and abrasion *least severe*
- Weathering and edge damage
- Weathering, abrasion and edge damage
- Weathering and ingress of dirt
- Weathering, abrasion, ingress of dirt and edge damage *most severe*

Webbing type 6 did not follow this trend, however, with the effect of weathering and ingress of dirt having less damaging an effect than weathering, abrasion and edge damage. The difference between these two results is so large that is unlikely to be the result of statistical variation. Webbing type 2, also does not appear to follow the trend with a slightly higher average breaking strength result for weathering, abrasion and edge damage, compared to weathering and ingress of dirt. This difference between the results however, is within one standard deviation and so cannot be said to be significant. Further testing of webbing type 2 would be necessary to show whether or not this material does follow the trend shown by the other samples.

Webbing 1 consistently achieved the lowest results throughout the test programme, whilst webbing 2 consistently achieved the highest results.

It was expected that the most severe combination of damage would be that with the largest number of damaging factors, i.e. WAIE and this was found to be the case. It was also expected that the greater the number of damaging effects the webbings were exposed to, the greater their loss of strength, and this was also found to be the case. It was not expected that the second most damaging effect for the majority of webbing types would be a combination of only two factors, weathering and ingress of dirt. This proves that, of all the combinations of damage used for this test programme, the damage caused by ingress of dirt is the most significant factor.

Whilst the other combinations of damage caused losses of strength, and these losses in strength became greater the more factors there were involved, the damage caused by internal abrasion of dirt particles within the webbing was most detrimental.

The damage by ingress of dirt has been examined in a previous research report [Robinson, 2006], and is well documented there. The results of those findings compare favourably with the results obtained in this research.

5 CONCLUSIONS

1. The most severe combination of effects was that of weathering, abrasion, ingress of dirt and edge damage (WAIE).
2. The second most severe combination of effects affecting breaking strength and elongation to failure was weathering and ingress of dirt (WI).
3. The second most severe combination of effects affecting energy absorbed to failure was weathering, abrasion and edge damage (WAE).
4. The least severe combination of effects was that of weathering and abrasion (WA).
5. Weathering and ingress of dirt (WI) was found to be the most significant damaging combination in this study.
6. Webbing 1 consistently achieved the lowest results throughout the test programme, whilst webbing 2 consistently achieved the highest results.
7. Webbing 11 showed the largest average reduction in strength of 40.9% when exposed to the combined effects of weathering, abrasion, ingress of dirt and edge damage
8. Webbing 8 showed the largest average reduction in elongation to failure of 29.5 % after exposure to weathering and ingress of dirt.
9. Webbing 6 showed the largest average reduction in energy absorbed to failure, of 58% after exposure to weathering, abrasion, ingress of dirt and edge damage.
10. There was no apparent correlation between the failure mode of the webbing samples and the loads obtained.

6 RECOMMENDATIONS

The results obtained in this study highlight how combinations of relatively small amounts of damage can have a severe effect on the tensile properties of webbings. In a dynamic fall situation, these combinations of effects could have an equal or more severe effect on the dynamic performance of webbings. A study into the effects of combinations of damage on the dynamic performance of the webbings is highly recommended. A technique was developed by the author to dynamically test webbing samples, and would be suitable for such a study.

L Robinson, *Development of a technique to measure the dynamic loading of safety harness and lanyard webbing*, HSL/2006/37, 2006.

http://www.hse.gov.uk/research/hsl_pdf/2006/hsl0637.pdf.

The combination of weathering, ingress of dirt and edge damage was not investigated in the current programme. The effects of this damage on the tensile properties of the webbing are expected to be severe and similar to weathering, abrasion, ingress of dirt and edge damage. There may be some value in conducting these tests to explore this combination.

Wetting and drying cycles may prove a valuable condition to investigate, eliminating sunlight and abrasion effects from outdoor weathering. The effect of several wetting and drying cycles on the webbing, using both rain and tap water may affect to some extent the properties of the webbings.

A study into the effects of melting damage and its interaction with other damaging effects is also recommended. Previous examinations of harnesses removed from service have revealed many occurrences of melting damage. Pin-point sized melting damage typical of that seen arising from sparks, as well as larger, more localised damage would be studied initially, including the effects of position of the melting damage (middle or edge) on the tensile properties of webbing. This study could then be expanded to include the combined effects of melting and abrasion, melting and edge damage etc. It is possible that areas of melting damage may act as easy paths for failures to propagate under tensile loads, and combined with effects such as weathering and/or abrasion and edge damage could have a strongly deleterious affect on the tensile and dynamic properties of webbings.

7 REFERENCES

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8 APPENDIX

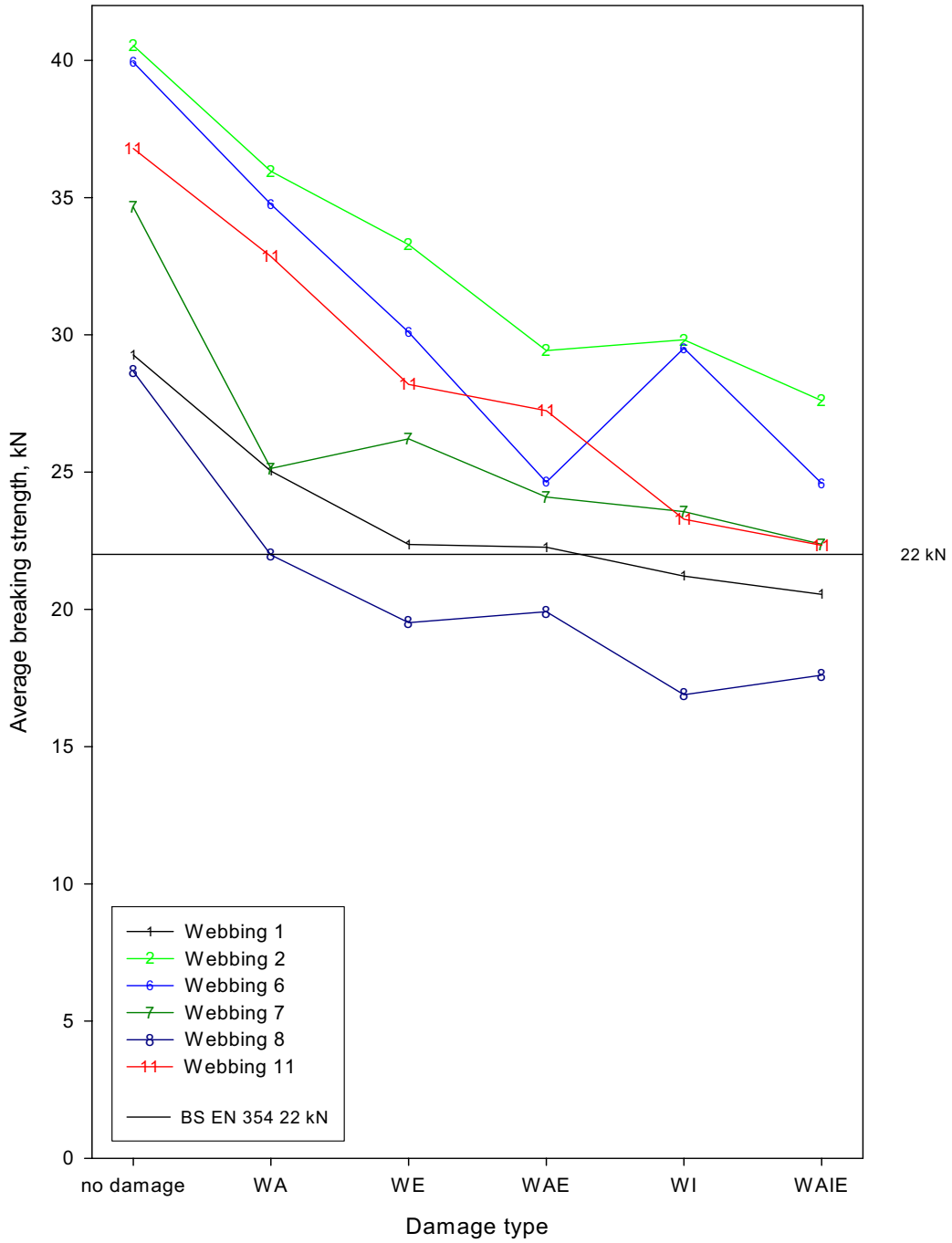


Figure A1. Average breaking strength for each combination of damage

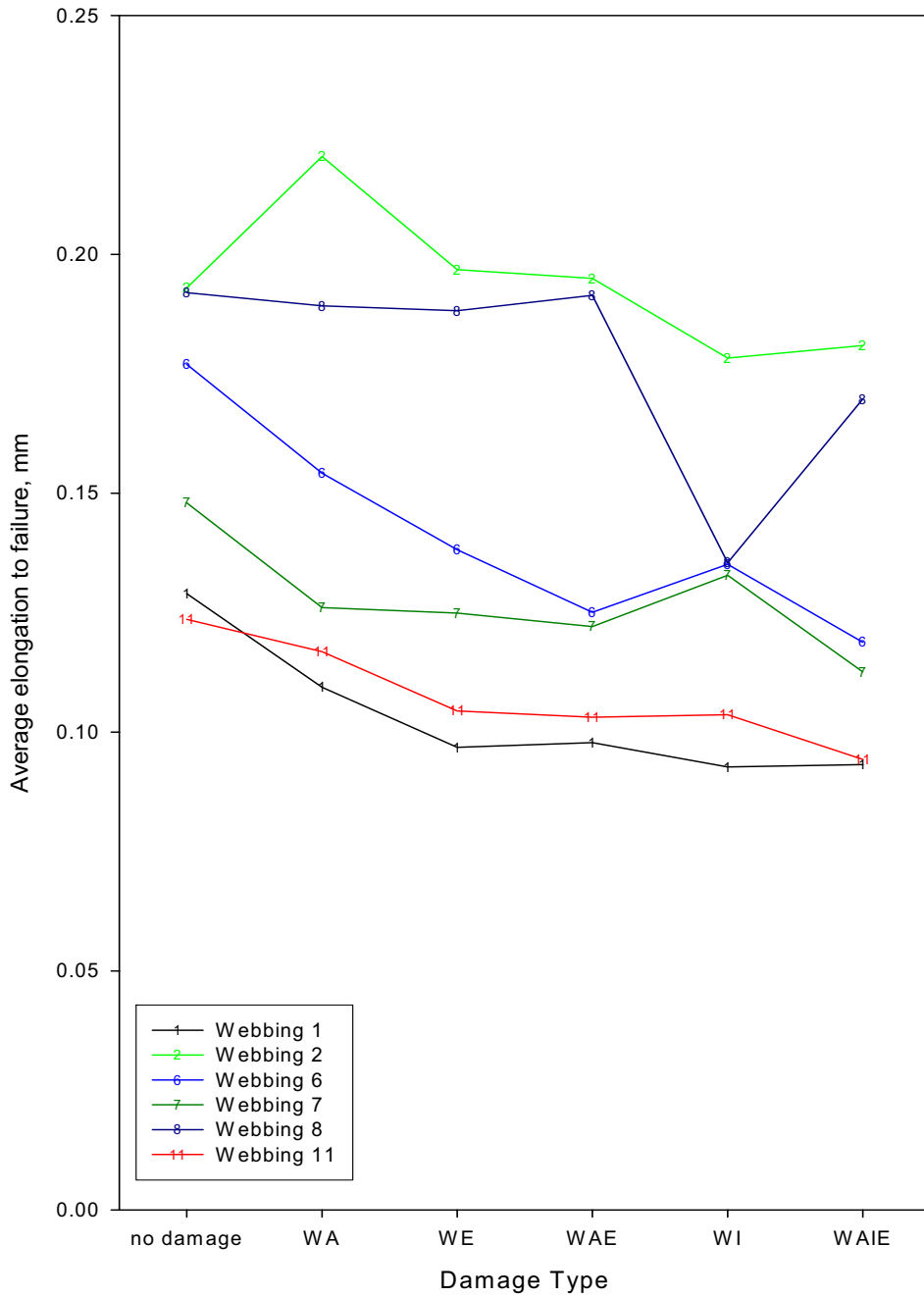


Figure A2. Average elongation to failure for each combination of damage

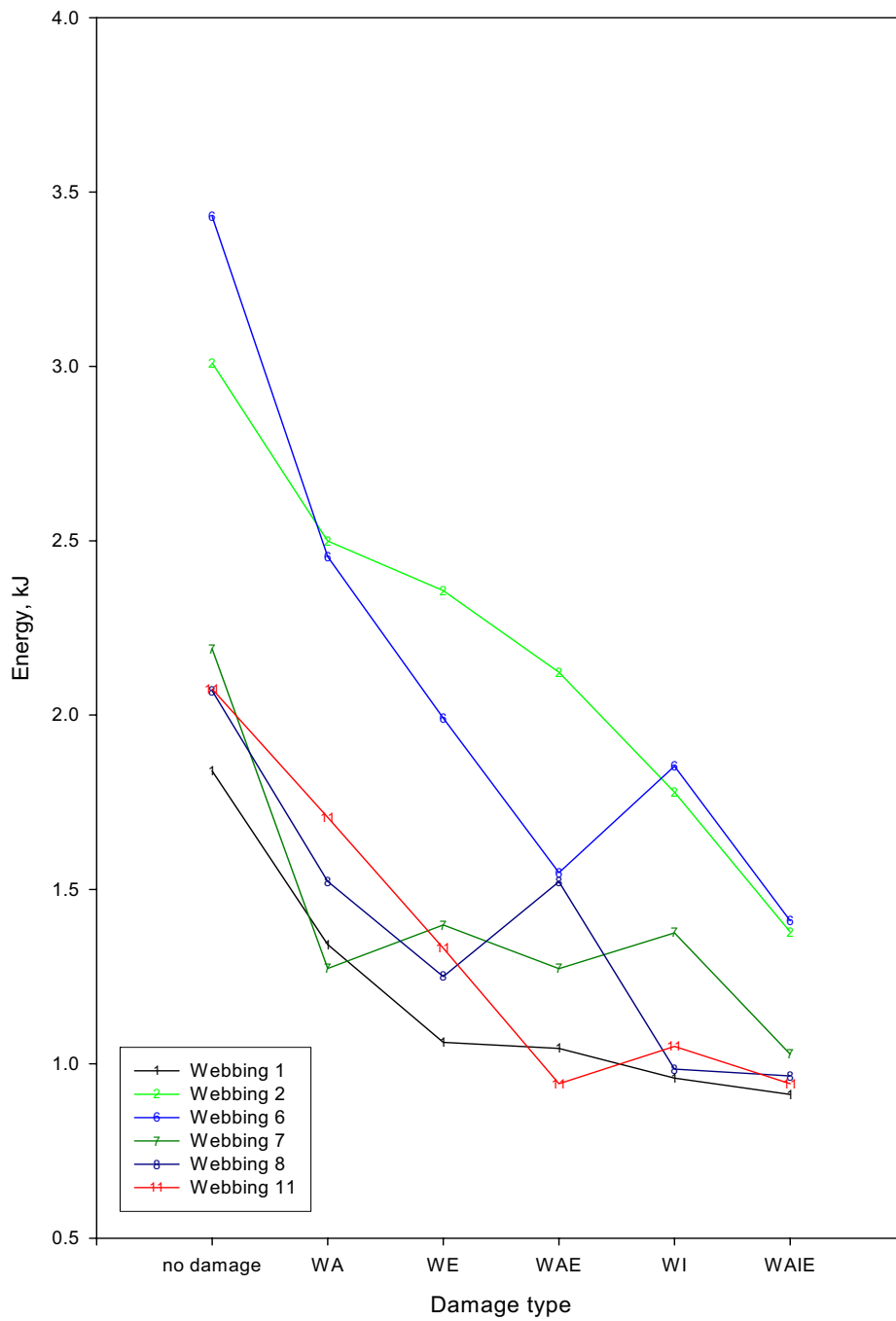


Figure A3. Average energy to failure for each combination of damage

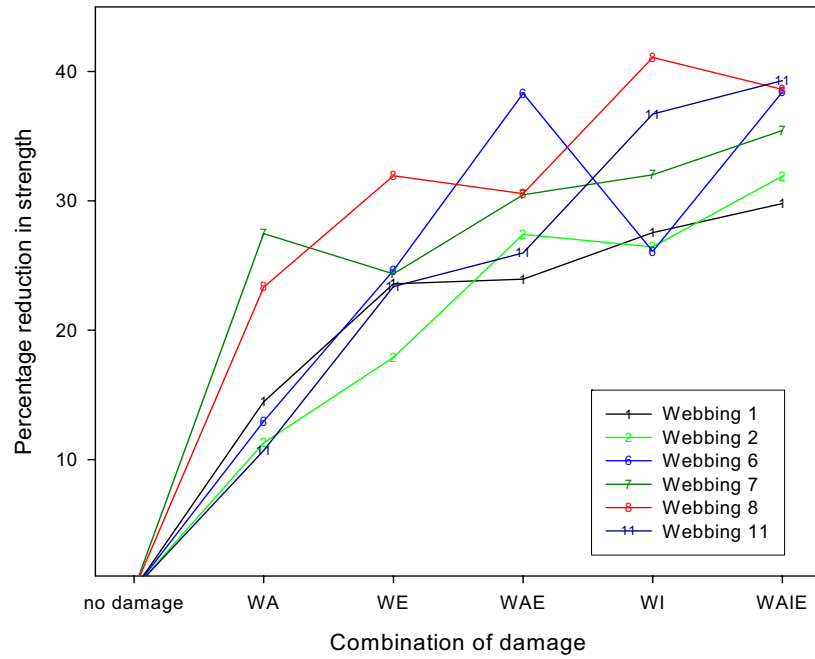


Figure A4. Average percentage reduction in breaking strengths for each combination of damage

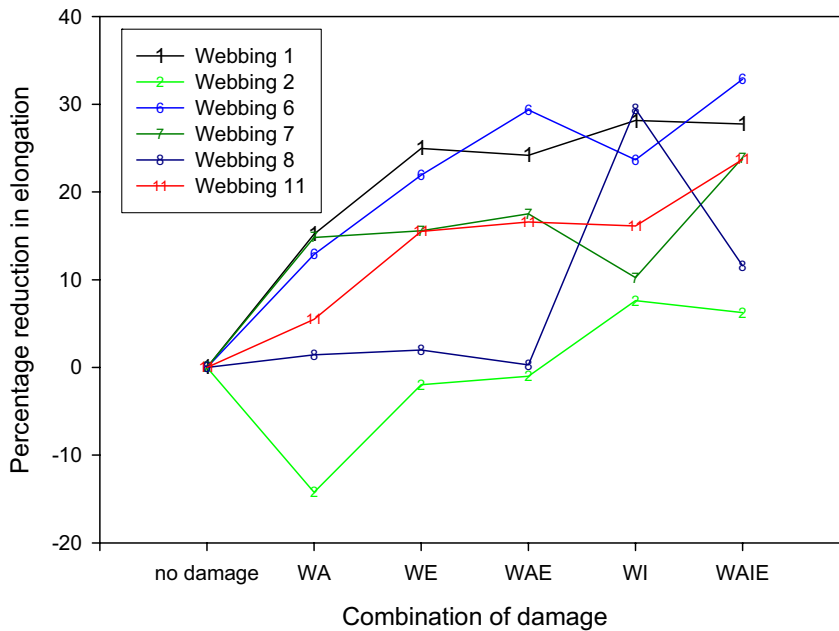


Figure A5. Average percentage reduction in elongation to failure for each combination of damage

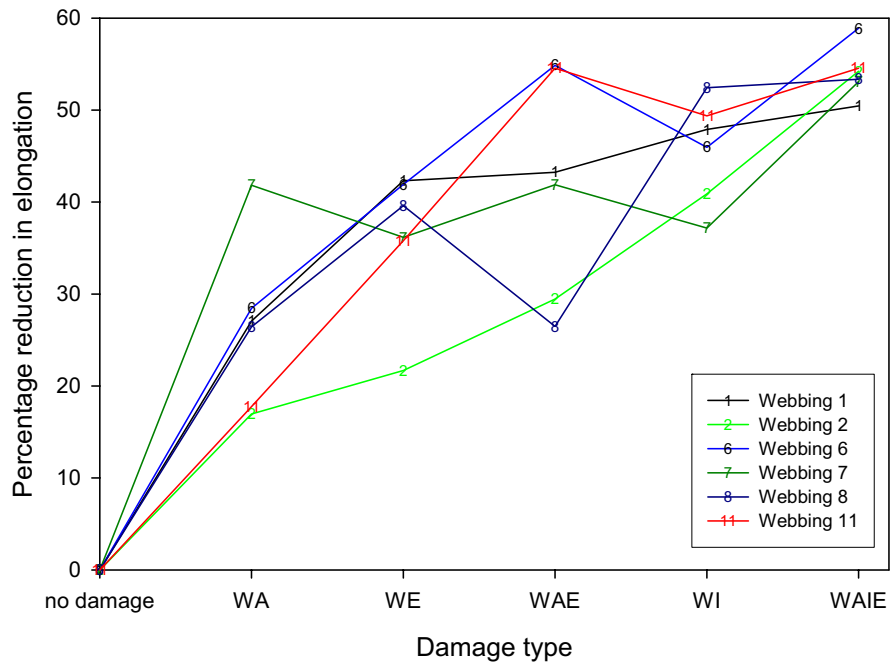


Figure A6. Average percentage reduction in energy absorbed to failure for each combination of damage