Factors Influencing the Effective Life of Chainsaw Protective Legwear

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ABSTRACT

In 1983, chainsaw cuts to the leg accounted for 29% of all reported lost time accidents in the New Zealand logging industry. The introduction of protective legwear reduced this figure to 8% in 1986. Since this time chainsaw cuts to the leg have continued to account for more than 5% of all injuries. There were several possible explanations for this failure to eliminate chainsaw cuts to the leg, including the deterioration of the protective legwear over time. Therefore, two research projects were established. The first attempted to find out how long the legwear was able to protect the user at the level required by the New Zealand Standard. This research found that the legwear failed after 6 months use by loggers working in New Zealand plantation forests. The second project was established to determine which factors caused the deterioration of the legwear's protective properties. This project found that exposure to even small quantities of oil resulted in the legwear comprehensively failing the New Zealand Standards test.

Keywords: Chainsaw, protective legwear, cut-resistant legwear, deterioration, chaps

INTRODUCTION

Cut-resistant legwear consists of many small strands woven into a matt-like material. Each protective garment contains 6-8 layers of this material. When the chainsaw cuts through the outer cover, the teeth in the chain grab these small strands, pulling them out of the garment and into the drive sprocket of the chainsaw. This clogs the chainsaw's drive sprocket and stops the chain from rotating. In New Zealand there are two types of cut-resistant legwear - chainsaw trousers and chainsaw chaps. The trousers have protective material sewn inside to protect the front and side of the leg, with the outer material covering the back of the legs. Chaps contain protective material, which also cover the front and sides of the leg, but are open at the back to facilitate cooling.

Figure 1 illustrates the proportion and number of all lost time injuries that were chainsaw cuts to the leg (a lost time injury is defined as an injury which causes a worker to miss the next scheduled full day's work). This shows an initial dramatic decline from 1983, where chainsaw cuts to the leg accounted for 29% of all reported lost time injuries, to 1986 where this figure was only 8%. This decline was attributed to the introduction and compulsory use of protective legwear [3].

Figure 1 also shows that from 1986 until 1994, chainsaw lacerations to the leg fluctuated between 6-11% of all reported lost time injuries. However, in 1994 the use of protective legwear with the S-mark was made compulsory in the New Zealand logging industry. S-Mark certification provides evidence that the legwear is certified to be of the level required by the New Zealand Standard [6]. The compulsory use of S-Marked legwear resulted in a further small decrease in the number and percentage of chainsaw lacerations to the leg. Figure 1 shows that the introduction of cut-resistant legwear and the S-Mark did not totally eliminate chainsaw cuts to the leg.

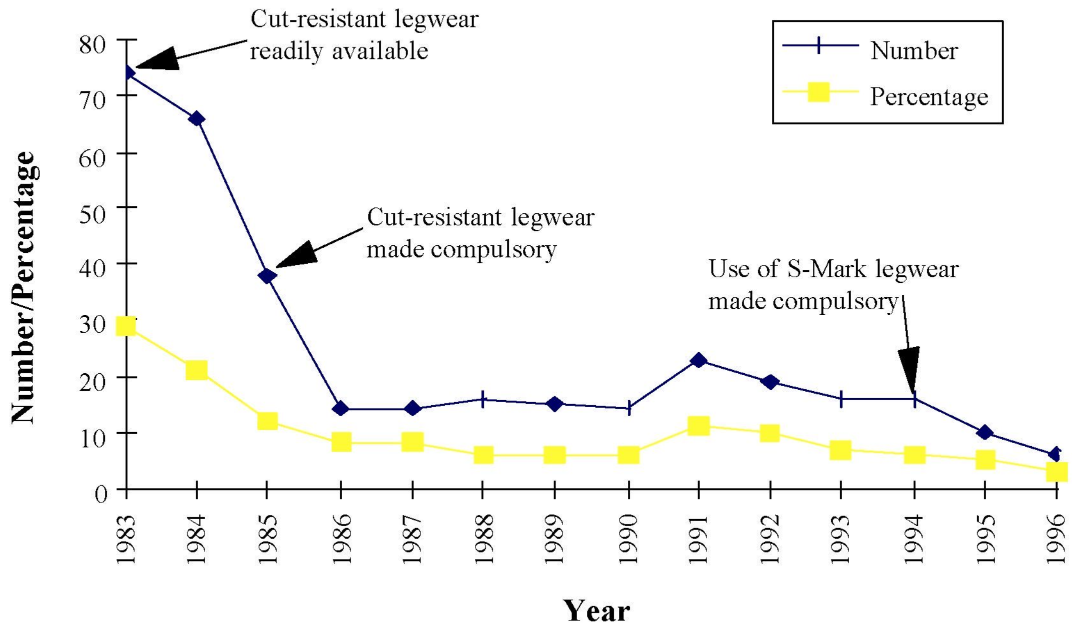

Figure 1 - Chainsaw cuts to the leg - 1983 to 1996

One of the most obvious reasons for the failure of protective legwear to eliminate all chainsaw cuts to the leg, is the fact that protective legwear is *cut-resistant*, not *cut-proof*. In New Zealand, protective legwear is designed to completely prevent an injury when the chainsaw has a chain speed of 20 m/sec. A large number of professional chainsaws can produce a chain speed higher than this, some even up to 34 m/sec. There is protective legwear available in Scandinavia that can provide protection up to 28 m/sec. However, in New Zealand's sub-tropical climate the thermal properties of these garments would place an unacceptably high amount of heat stress upon the wearer. Since thermal comfort has been identified as the most important factor affecting wearer acceptance of protective clothing [2], it is extremely unlikely that loggers would accept protective legwear that produced a higher level of thermal discomfort than those currently worn. In other words, a compromise has been made between the needs of the worker to be protected from the chainsaw, and the needs of the worker to be protected from heat stress.

Secondly, the protective properties of the legwear may deteriorate with age, cuts, nicks, washing and exposure to solvents. The lack of research to quantify the possible deterioration of the legwear has resulted in an absence of firm replacement guidelines. Consequently, there is a widely held belief that the legwear will last at least 12 months.

A small number of laboratory-based studies have investigated the factors which impact on the cut-resistance of protective legwear [1, 7]. Arteau, Arcand & Turcot [1] found factors such as the sharpness of the chainsaw chain, chain type, angle of cutters, condition of the clutch, gasoline and oil mixture and the chainsaw's stability significantly affected the chain speed that the legwear could resist.

Putnam, Jackson and Davis [7] found that washing and drying protective pads resulted in a small decrease in the maximum chain speed the pads were able to resist. Arteau et al. [1] also cite unpublished British research (Satra, UK) as showing a systematic decrease in performance with washing. Putnam et al. [7] also found that petrol and oil had no impact on the maximum chain speed the protective pads could pass. However, this research [7] used very small sample sizes (1-4 pads). The New Zealand Standard requires a much higher level of protection than that found in any of the pads Putnam, et al. [7] tested and the protective pad design was different from those manufactured in New Zealand. The impact of age, solvents, and washing on the cut-resistance of the legwear will vary according to the properties of the materials that make up the protective legwear. Therefore, results from overseas studies are probably not applicable to protective legwear in New Zealand.

Therefore, a study was established to find out how long the legwear was able to protect the wearer at the level required by the New Zealand Standard and investigate which factors reduce the legwear's protective properties.

EXPERIMENT 1

METHOD

Subjects

The subjects were 12 full time chainsaw operators working in clearfell logging operations within the Bay of Plenty region in the central North Island of New Zealand.

Experimental Design

Eighteen pairs of "S-marked" chaps, which had been manufactured in accordance with the New Zealand Standard (NZS 5840), were purchased directly from the manufacturers. Six of the chaps were immediately sent for destructive cut testing. The other twelve pairs were distributed to the operators.

As the New Zealand Standard requires six pairs of chaps for a full Standards test, it was planned to destructively cut test six pairs of chaps after three months' use and six pairs after six months' use by the subjects in their normal operations. In order to determine how long the chaps offered the level of protection required by the New Zealand Standard, the left leg was tested in accordance with NZS 5840.

Test Procedure : NZS 5840

The left leg was used for destructive cut-testing to the New Zealand Standard, as anecdotal evidence suggests this leg is subjected to more oil/petrol spills and wear. The left leg of the chaps was buckled to the leg form of the test rig. A bar exerting a force of 50 Newton/metres was placed on the chap's buckled straps to hold the chap against the test rig. The bar of the electric test saw was set 1mm above and at 45° to the chap leg, then the chain was accelerated to 20 m/sec. At the same instant as the saw was released on to the chap leg, the power supply to the electric motor was cut off.

Each leg was cut once, with three of the six pairs being cut at 50cm from the top of the waistband and three at 80cm. A pass was achieved if the test rig foam pad, positioned on the leg form under the chap, was unmarked by the chainsaw upon the completion of all six tests.

Chap Use

Each operator was given a record book and asked to record when the chaps were worn, how the chaps were stored, whether they were washed, and any major oil/petrol contamination and/or damage. Regular follow-up was made by both the contractor (daily) and the researcher (weekly) to ensure accurate records were maintained. The chainsaw operators were also instructed not to repair or re-cover the chaps.

RESULTS

Table 1 contains information on chap condition and use obtained from the operator's record book. The comments were derived from a pre-test inspection by the researcher, and important comments by the operator. There are several notable features shown in Table 1. Most loggers store their chaps in the work van or at home. Only one of the samples was stored on the ground in the forest.

Almost all the chaps (80%) had small nicks or cuts, but only two of these (samples 7 and 8) resulted in visible damage to the protective pad. The outer materials of all samples had a coating of mud, petrol and oil, with samples 7, 8, 10, 12 and 13 being saturated in oil and/or mud. Sample 16 was the only pair to be accidentally soaked in diesel. Only one pair of chaps (sample 16) was washed regularly, three pairs were never washed (samples 8, 11, 15) and the remainder were washed infrequently. Two pairs of chaps designated for testing at three months were stolen, hence information on these chaps are not included in the results.

Table 1 - Chap condition and use

Sample	Task	Storage	Washes	Nicks/Cuts	Comments
7	Fell	work van	4 warm	large rip in left outer, small holes in right	Soaked with oil/petrol, pad slightly damaged, no buckles
8	Fell some skidwork	work van	none	lower left small tear	Very muddy, pad hanging out tear in outer
9	Felling	work van	1 warm	little nick in left outer and three on right leg	Pad appeared undamaged
10	Fell some machine op	porch	1 warm, 1 cold	none	Oily, pad undamaged
11	Felling	home	none	small nick low left	Pad undamaged
12	Felling	work van	1 cold	small nick on left leg	Very oily and muddy, pad undamaged
13	Fell and skidwork	work van	1 warm 4 cold	small nick mid-right leg	Very oily and muddy, pad undamaged
14	Skidwork some fell	work van	2 cold 1 warm	small nicks left and right lower	Pad undamaged
15	Fell some machine op	work van	none	none	Pad undamaged
16	Fell some machine op	bush and van	19 cold	small nick left lower	Soaked in oil, some diesel exposure, pad undamaged

Table 2 contains a summary of the results of testing the left leg to NZS 5840. All six pairs of the new chaps passed the test. After three months, only four pairs of chaps could be recovered. One of the four pairs recovered had all of its buckles removed. The removal of the buckles from one of this sample prevented the chaps from being secured to the test rig in the regulation manner, invalidating the test. The remaining three pairs all passed, although this could not be considered a pass according to the New Zealand Standard, as only three legs were tested. After six months of use in production logging operations, three of the six pairs of chaps failed.

Table 2 - New Zealand Standards test (left leg)

Samples	Time in Use (Months)	Mean Weight grams(± SD)	Chain Speed (m/sec)	Percentage Pass
1-6	0	642.2 (± 6.6)	20	100%
7-10	3	804.5 (± 51.0)	20	100%*
11-16	6	833.7 (± 44.3)	20	50%

* This could not be considered a NZS 5840 pass, as only three pairs could be tested

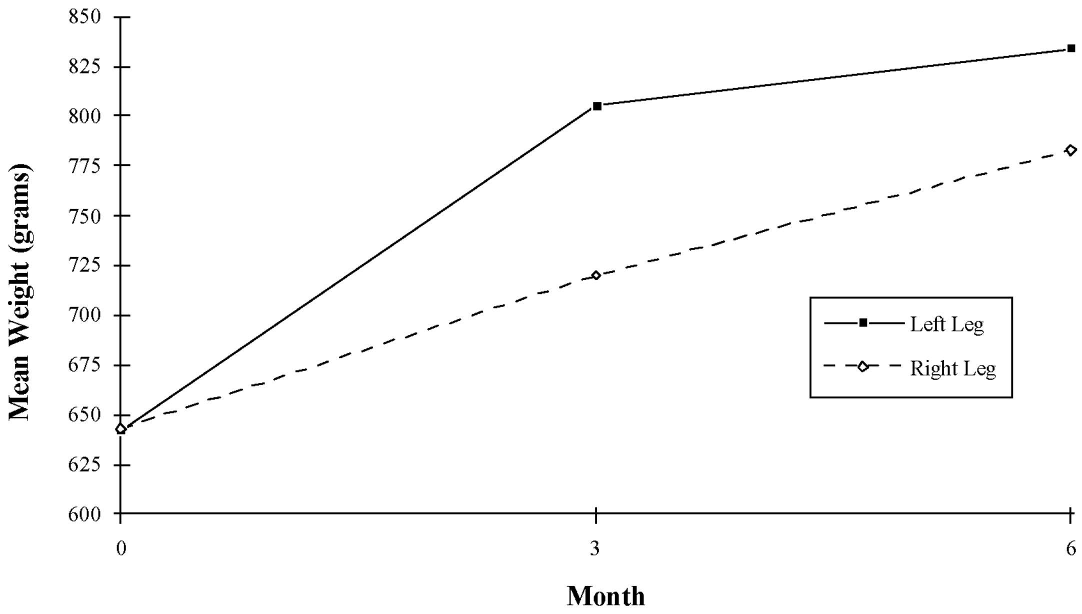

Figure 2 - Change in mean chap leg weight

Figure 2 shows that the mean weight of both chap legs increased with increasing use. This was due to the retention of oil, petrol, earth, and water by the legwear. Although statistically insignificant ($P > 0.05$), the left leg increased both at a higher rate, and to a higher level than the right leg.

DISCUSSION

All six pairs of the new chaps passed the cut-test, thereby passing the New Zealand Standard. After three months' use in clearfell logging conditions, the full New Zealand Standards test could not be performed, as only four samples could be recovered. Unfortunately, the buckles had been removed from one of the four pairs that were recovered. This meant that the legwear could not be secured to the test rig in the regulation manner, which invalidated the test. All of the three remaining pairs of chaps passed. However, this could not be considered a pass in terms of the NZ Standard, as only three pairs were tested.

After six months, all six remaining pairs of chaps were recovered and cut tested. Only one of the six pairs needs to fail for the legwear to fail the New Zealand standards test. In this case three pairs of chaps passed and three failed. This finding caused a great deal of concern because the chaps are normally worn for many years!

The presence of nicks/cuts does not appear to have affected the result of the test at three or six months. Even when the protective pads were visibly damaged, the leg still passed. The higher weight of the left leg provides some evidence to support the anecdotal evidence which suggests that the left leg is subjected to a greater amount of petrol/oil contamination, but there was no evidence to suggest that the left leg was subject to more wear.

Washing appears to have affected the result of the test. Two of the three legs that passed at six months had never been washed, while all three pairs that failed had been washed at least once. The samples that failed also appeared to have a higher level of oil and petrol contamination than those that passed. However, due to the small sample size, the large number of confounding variables, and the experimental design, no firm conclusions can be made regarding which factors caused the legwear's deterioration.

This research found that after six months use by full time loggers the level of cut protection offered by the protective legwear had deteriorated to a level below that required by the New Zealand Standard. That study highlighted the need for further research to identify which factors contributed to the deterioration of the protective material. Although the study identified a number of factors as being important, given the research methodology it was not possible to identify which factor(s) were responsible for the legwear's deterioration. Factors that may have had an impact and required further investigation were washing, and exposure to petrol and oil. As a result, a second study was planned to find out which of these three factors caused the legwear to fail.

EXPERIMENT 2

METHODOLOGY

Thirty pairs of "S-Marked" chaps, which had been manufactured in accordance with the New Zealand Standard [6] were purchased directly from the manufacturers. The chaps all came from the same batch to prevent any possible variations in the quality. See Table 3 for the experimental design. Table 3 shows the type and amount of each treatment that the legwear was exposed to. Group label indicates what the legwear was exposed to, and how many times it was exposed (e.g. Wash2 was in the wash group and was washed twice).

In accordance with the New Zealand Standard, six legs were tested in each group. The third column shows the quantity of the three treatments that the legwear was exposed to at a time. The fourth column contains information on the number of treatments the legwear had, and the fifth column contains the total quantity of petrol, oil and washing that the legwear was exposed to.

Control
Six chap legs were not washed and were not exposed to oil or petrol, but were stored in a box for the duration of the experiment.

Washing
The chaps were washed by the same methods used by the loggers in the previous experiment. The chaps were machine washed in a Fisher and Paykel OW51 Smart Drive on "normal cycle", with a wash temperature of "cold". In accordance with Cold Powers™ recommendations for "Heavily Soiled" clothing, two cups (400ml) of Cold Power washing powder were used for each wash. This type of washing was not necessarily the manufacturers recommendations, but was done because this is how chaps are washed by loggers in reality.

Table 3 - Type and amount of exposure

Group Label	Number of Legs	Quantity exposed to at a time	x	Number of Treatments	=	Total quantity of exposure
Control	6 Legs	Nil		Nil		Nil
Wash 2	6 Legs	1 wash		2		2 washes
Wash 5	6 Legs	1 wash		5		5 washes
Wash 10	6 Legs	1 wash		10		10 washes
Oil 2	6 Legs	0.25L of oil		2		0.50L of oil
Oil 5	6 Legs	0.25L of oil		5		1.25L of oil
Oil 10	6 Legs	0.25L of oil		10		2.50L of oil
Petrol 2	6 Legs	0.85L of petrol		2		1.70L of petrol
Petrol 5	6 Legs	0.85L of petrol		5		4.25L of petrol
Petrol 10	6 Legs	0.85L of petrol		10		8.50L of petrol

Petrol

The petrol used in this case was 91 octane petrol, with a 30:1 mix of two stroke oil (i.e. 30 litres of petrol to 1 litre of two stroke oil). Petrol exposure was measured in terms of chainsaw petrol tanks, to make the volumes easier for chainsaw operators to visualise. A Husqvarna 288, which has a petrol tank size of 0.85L, was chosen as the "typical" size for chainsaw operators working in clearfell. Each tank (0.85L) of petrol was spread evenly over each chap leg and left to be absorbed by the fabric.

Oil

As with petrol, exposure to chainsaw bar lube oil was measured in terms of Husqvarna 288 oil tanks (0.5L). However, as the protective legwear's ability to soak up the oil was not as good as expected, the application rate was half a tank. Each half tank (0.25L) of oil was spread evenly over each chap leg and left to be absorbed by the fabric.

Storage of Chaps for Drying

After each treatment (wash, exposure to 0.25L of oil, exposure to 0.85L of petrol) the chaps were dried. As with previous textiles research [5], the chaps were dried at room temperature for at least 24 hours after each wash or exposure to petrol or oil. The different treatment groups (oil, petrol and washing) were stored separately to avoid contamination. The chaps were laid flat to dry, on the shelves of a storeroom. Storage and treatment of the chaps was undertaken away from sunlight, in case sunlight exposure affected the chaps performance.

To allow an estimation of the amount of extra material (oil, petrol and washing powder) retained by the chap, the chaps were weighed before the experiment began and prior to cut-testing. Once the total number of exposures had been completed, the legwear was sent off for cut-testing.

Test Procedure: NZS 5840

The chaps were cut tested according to the New Zealand Standard [6], procedure outlined in the previous experiment.

RESULTS

Table 4 contains the information on mean chap weights, the number and percentage of layers cut through and whether the chaps passed or failed. As would be expected, the weight of the control group did not change at all.

Table 4 - Results of exposure and testing

Group	Mean weight Before (grams)	Mean weight After (grams)	Mean number of layers cut through (out of 6)	Percent layers cut through (Mean)	Pass/Fail
Control	952.6	952.6	4.2 ± 0.7	70%	Pass
Wash 2	982.8	982.8	5.5 ± 0.5	92%	Pass
Wash 5	967.7	997.9	5.0 ± 0.6	83%	Pass
Wash 10	967.7	997.9	5.3 ± 0.5	88%	Pass
Petrol 2	952.6	1088.6	4.5 ± 0.5	75%	Pass
Petrol 5	997.9	1134.0	4.2 ± 0.4	70%	Pass
Petrol 10	952.6	1118.9	5.0 ± 0.6	83%	Pass
Oil 2	**967.7**	**1814.7**	$\mathbf{6.0 \pm 0.0}$	**100%**	**Fail**
Oil 5	**997.9**	**2767.0**	$\mathbf{6.0 \pm 0.0}$	**100%**	**Fail**
Oil 10	**952.6**	**2812.3**	$\mathbf{6.0 \pm 0.0}$	**100%**	**Fail**

The chaps that were washed twice did not increase in weight, while those washed five and ten times increased slightly. This slight increase could be either residual dampness or the retention of washing powder residue. The chaps exposed to petrol all increased in weight slightly. This increase must be due to the retention of residue from exposure to the petrol. All chaps that were exposed to oil increased dramatically, indicating that the oil soaked into, and accumulated inside the chap legs.

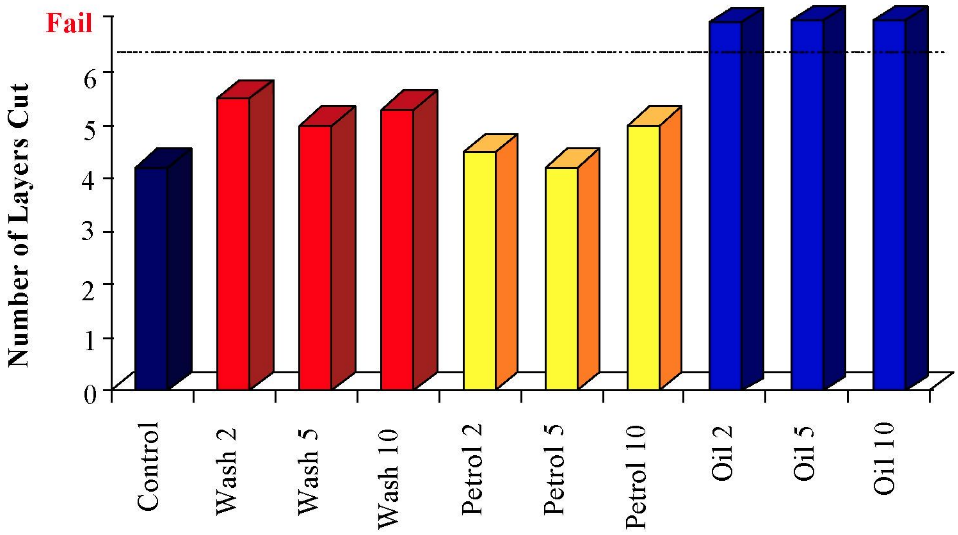

Figure 3 - Chap performance

Figure 3 graphically illustrates the performance of the chaps, in terms of the mean number of layers that were cut through for each group of six chap legs, after cut testing to the New Zealand Standard. Each bar consists of the average of the six legs in that group. In the control group, on average, the cut test resulted in 70% of the six layers being cut through. After exposure to petrol, on average 76% (range 70-83%) of the layers were cut through. Surprisingly, the mean number of layers cut through did not increase linearly with an increase in exposure to the petrol. After the chaps had been washed, on average 88% (range 83-92%) of the layers were cut through. Again the mean number of layers cut did not increase linearly with an increase in the number of washes.

Only one of the six legs in each group needs to fail for that group to fail the New Zealand Standards test. However, in all three oil exposed groups, all six chap legs failed. In fact, the chainsaw cut through all six layers of the protective material so easily, it damaged the leg form of the test rig.

DISCUSSION

All eighteen legs that were exposed to even the smallest amount of oil (0.5L) comprehensively failed. They provided such a small amount of resistance to the chainsaw, that the chainsaw cut through the legwear and into the part of the test rig underneath the legwear. According to the legwear manufacturers, oil exposure caused failure of the legwear by accumulating on the internal fibres of the legwear, thereby increasing the internal friction between the strands. When the strands were touched by the chainsaw, the internal fiction caused the strand to be cut through, rather than being pulled out and clogging the chainsaw as they were designed to. Therefore, manufacturers should develop an oil proof outer to prevent the oil being absorbed into the protective material. However, the oil proof outer must not increase the heat retention of the legwear, since thermal comfort has been identified as the most important factor affecting wearer acceptance of protective clothing [2]. Since chaps exposed to even the smallest quantity of oil (0.5L) failed, further research is needed to find out whether exposure to smaller quantities of oil also cause chap failure.

On average the number of layers cut through after exposure to petrol (76%) were similar to the control (70%). However, after washing, on average the number of layers cut through (88%) was clearly greater than the control group (70%). According to legwear manufacturers, washing causes the layers of protective materials to tangle slightly, resulting in a small increase in the internal friction between the strands. This slight increase resulted in a greater number of layers being cut through than the control and petrol exposed chaps, but not as much as those exposed to oil.

These results support the assertion that overseas research may not be applicable to protective legwear manufactured in New Zealand, as overseas research [7] found oil had no effect on the legwear's protective properties. In agreement with this research [7], petrol appeared to have no impact, while washing seemed to result in a minor increase in the number of layers that were cut through.

Figure 2 also shows that the number of layers cut did not increase in a linear manner with an increase in exposure to washing or petrol. The reasons for this could be either small variations in the quality of the legwear, or in the quality of the cut testing. Arteau et al. [1] found factors such as the sharpness of the chain, recency of sharpening, chain type, precise angle of the chain teeth, condition of the clutch, petrol/oil mix, and the stability of the chainsaw could affect the chain speed that the legwear could resist. In the present study, it is possible that a small variation in a factor, such as the sharpness of the chainsaw chain may have resulted in the absence of a linear trend for washing and petrol exposure groups.

CONCLUSIONS

Legwear deteriorates to a level below that required by the New Zealand Standard [6], after six months use by logging workers. Legwear exposed to even the smallest quantity of oil (0.5L) comprehensively failed. Therefore, it appears likely that it was spilling oil on the legwear that caused the legwear to fail after six months use. Therefore, manufacturers have been advised to produce legwear with an oil proof outer, to prevent the oil soaking into the protective material. However, manufacturers have also been advised not to adversely affect the thermal properties of the protective legwear. The control, those exposed to washing and petrol all passed the New Zealand Standards test.

RECOMMENDATIONS

- Chainsaw operators should replace chaps which have been exposed to 0.5L of oil as they provide almost no protection against a chainsaw.

- Further research is also needed to investigate whether oil exposed chaps can be treated in some way (e.g. hot washed or washed in petrol) to remove the oil and restore the protection offered by the legwear.

- Another factor in need of further investigation is whether different types of washing and washing powder have any impact upon the chaps ability to pass the New Zealand Standards test.

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