HOW GLOVES FAIL

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ABSTRACT

Gloves are routinely used in industry to protect the wearer from injury and industrial diseases, but little is known about their effective service life or where and how they fail, as failed gloves tend to end as contaminated landfill. A commercial glove laundering operation has given a unique opportunity to investigate how gloves fail in many industries. Over 1000 dipped or partially dipped gloves were examined and it was found the most common mode of failure was at the base of the thumb, but failures between the fingers were also common. This appeared to relate to glove design and manufacture. Trials were also performed to determine the consistency of two human glove sorters when they re-sorted the same batch of gloves on different days. With further research to correlate glove appearance with glove performance, it should be possible to develop guidelines for determining the safe service life of gloves.

1. INTRODUCTION

In the past, the usage cycle of industrial gloves has been linear, with little opportunity for examination of how the gloves failed.

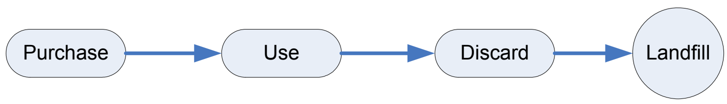

Figure 1 Linear management of gloves

Glove selection is commonly based on price rather than performance and service life is determined by smell or the obvious physical failure of the glove. Though the unit cost for new gloves could be low, they often fail to protect the wearer, as the initial selection was inappropriate for the task.

The development of commercial laundering processes and a management system (Figure 2) by one of us (BJ) has meant that the selection of gloves more appropriate for the task can be made in a cost effective manner. Quality gloves are laundered many times with little obvious change. They replace gloves purchased on price rather than performance that often fail in minutes. Recycling is viable despite the cost of glove collection and development of a propriety laundering process to maximise removal of visible contamination but minimise visible damage to the gloves.

The possibility of decontaminating gloves before reuse has been discussed by Perkins (1991) and successive thermal decontaminations of glove swatches has been demonstrated by research at NIOSH (Gao, El-Ayouby and Wassell 2005; Gao and Tomasovic 2005) to have limited effect on chemical breakthrough times and permeation rates. Other research on laundering of gloves and suits has tended to focus on pesticide residues rather than barrier performance (Branson and Rajadhyaksha 1988; Nelson, Laughlin et al. 1992; Keeble, Correll and Ehrich 1996; Miliken, Oakland and Hurwitz 1996; Perkins, Rigakis et al. 1996).

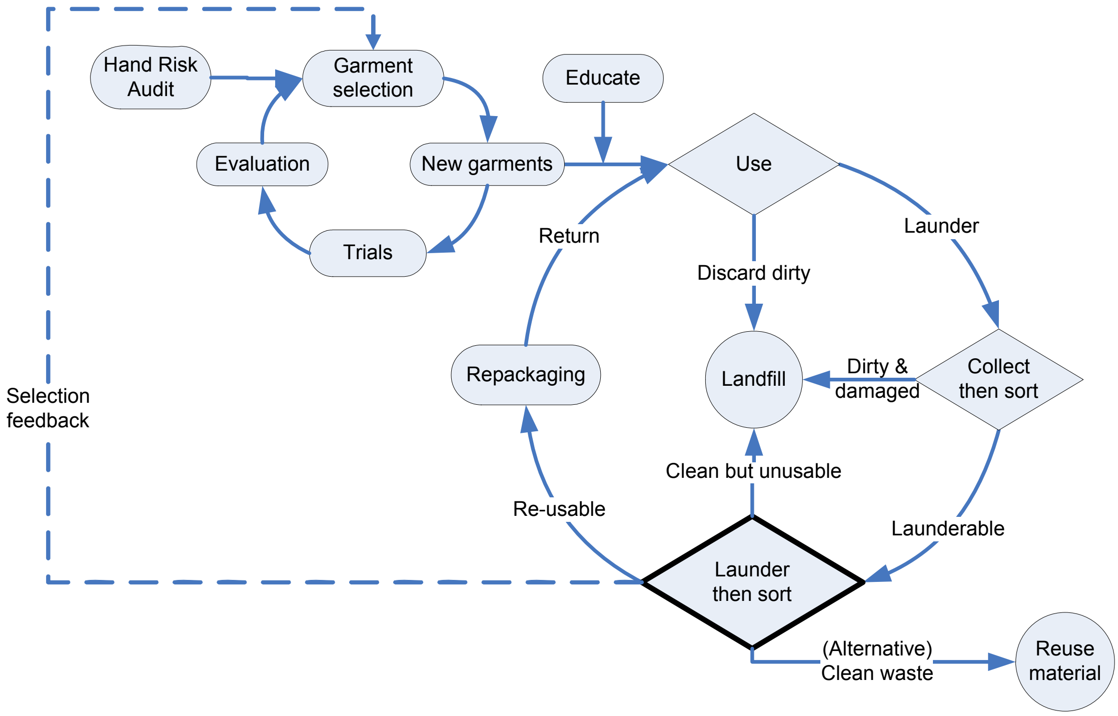

Figure 2 A new glove management system

There are numerous studies on the failure of disposable medical examination gloves and surgical gloves. Only one paper was found (Packham and Packham 2005) that indicated where industrial gloves fail. They were found to fail between the fingers and at the fingertips, but the proportions for each area and other details of failure were not given.

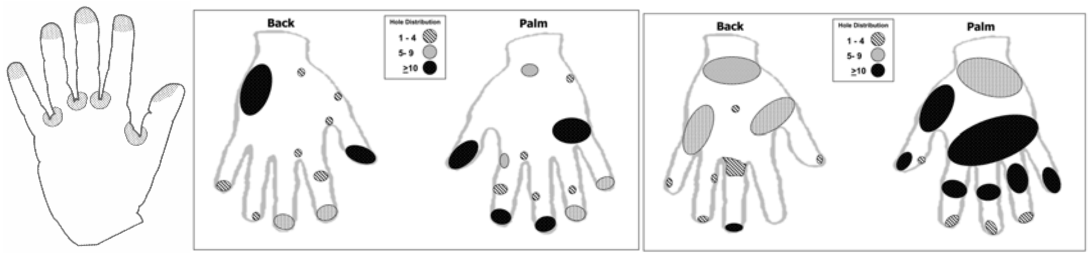

Figure 3 Industrial and clinical glove failure locations (Packham and Packham 2005) left, and (Kerr, Chaput et al. 2004) right figures

2. EXPERIMENTAL METHODS

A study was conducted involving 1000 gloves sent from different workplaces for laundering and recycling. In the initial sorting of gloves, those which were so heavily contaminated as to just spread the contamination though the washing machines were eliminated (see Figure 2). The remaining gloves were laundered and dried and then sorted.

Two experienced sorters were briefed on the trials and were able to identify why each glove that was rejected had failed. A classification scheme was developed (see

). The sorters were interviewed for each glove to determine the primary reason for failure, then asked if there were any other factors that would have lead to rejection of the glove. Each glove was numbered and later photographed back and front. The answers were coded on a spreadsheet (Excel, Microsoft). The spreadsheet was set up to automatically generate histograms of glove failure.

Table I Modes of failure of gloves in post-laundering sort

Code	Explanation
1	Penetration at base of thumb
2	penetration between first and second fingers “1/2”
3	penetration between second and third fingers “2/3”
4	penetration between third and little fingers “3/4”
a	Laundering damage
b	Damage to back of hand
c	Unclean cuff (aesthetic)
d	Discoloured (aesthetic)
e	Polymer coating breakdown
f	Damage to front of fingers
g	Will contaminate equipment
h	Hard – loss of plasticiser
i	Damage to fingertip thumb
j	Damage to index finger tip
k	Damage to second finger tip

Code	Explanation
l	Delamination of polymer coating
m	Damage to third finger tip
n	Damage to little finger tip
o	Old (partly aesthetic)
p	Damage to palm
q	Chemical damage
r	Torn or ragged cuff
s	No longer launderable
t	Damage to front of thumb
u	unclean after laundering
v	too dirty to launder
w	Worn (may also be old)
x	Excess (left or right)
z	Modified (often multilated)

To determine the reproducibility of the sorters and the variation between the sorters, a batch of 85 laundered gloves was sorted by both sorters on two separate days. Care was taken not to give hints on which gloves has previously failed to minimise bias in the results.

3. RESULTS

The overall pattern of failure has been sorted in order of primary failure and histograms show primary failure (black) and overall modes of failure (shaded) in the figure below. Trials with some gloves that were rejected before laundering are included in this figure (“too dirty to launder” and “will contaminate equipment”, but these numbers were usually quite low. Even mutilated gloves (some with fingers cut off) were laundered, as the laundered glove could be sent to clean landfill.

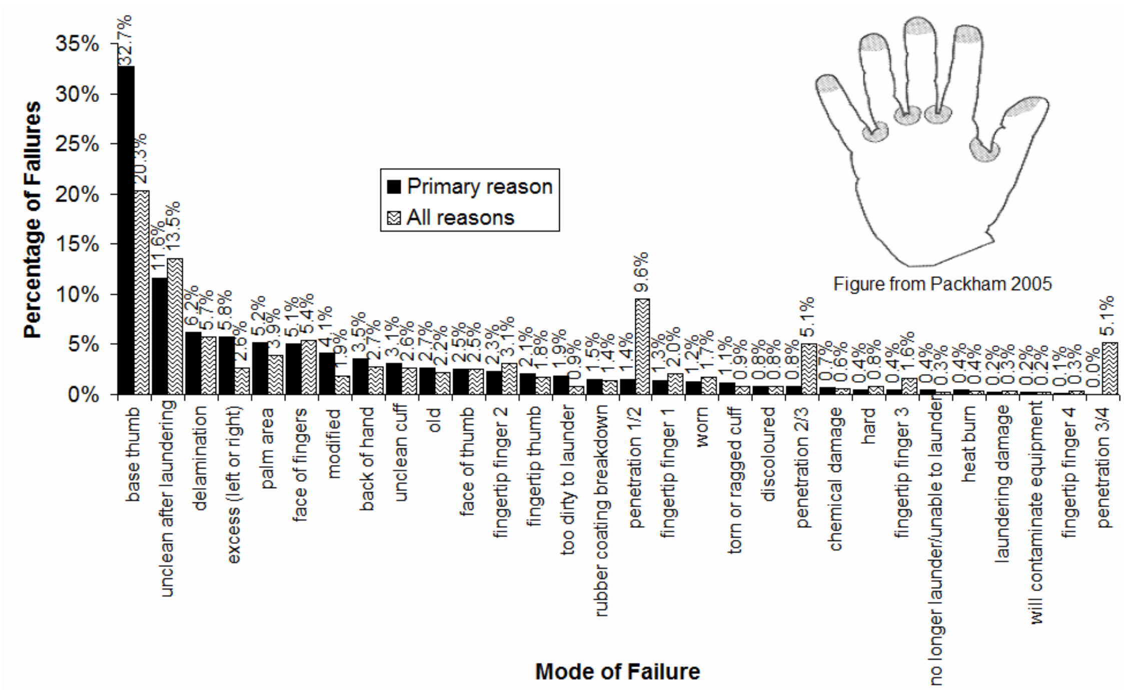

Figure 4 Failure of nitrile gloves (laundered and unlaundered)

Table II shows the level of consistency achieved by the two sorters when sorting the same batch of 85 gloves on successive days. An "inconsistency" was defined as a critical failure involving a penetration through the glove being missed in one of the trials and the glove not being rejected for another reason.

Table II Sorter Consistency (85 gloves)

Metric	Number	%
Sorter 1 rejected PM	15	18%
Sorter 1 rejected AM next day	16	19%
Sorter 2 rejected PM	37	44%
Sorter 2 rejected AM next day	36	42%
Sorter 1 consistency between days	82	96%
Sorter 2 consistency between days	70	82%
Number where only accepted 1 in 4 times	2	2%
Sorter 1 "inconsistency" in reason for rejection	0	0%
Sorter 2 "inconsistency" in reason for rejection	11	16%

4. DISCUSSION

4.1. How and why gloves fail

The most common primary mode of failure was a hole at the base of the thumb which accounted for 404 failures (20.3%) when all reasons for failure were analysed, though only 296 were picked up immediately (32.7% of primary failures). This tendency to select the base of the thumb first, when a glove also failed between fingers is shown by the apparently anomalous spikes for "all reasons" penetrations between the fingers (1/2, 2/3 and 3/4) as failure between fingers was also accompanied by failure at the base of the thumb.

It appears that gloves fail at the base of the thumb and between the fingers with industrial gloves and not with surgical gloves for several reasons. Firstly, industrial gloves are less elastic than surgical gloves, so tear more easily when stretched by movement of the fingers or thumb, particularly when the fabric was more elastic than the polymer coating. Secondly, the manufacturing process tend to produce seams in these areas and also to produce local thickening. A thicker layer cracks more easily than a thinner layer when bent.

The second most common reason for glove failure was that they were "unclean after laundering". This was differentiated from "unclean cuff" and "discoloured". "Unclean cuff" was usually rust or stains on a partially dipped nitrile glove, where the cuff was an elasticised fabric. "Discoloured" meant the glove was stained fairly uniformly, but did not show any residues. The cut-offs of acceptability of the laundered glove depended on standards of acceptability set by each workplace. Classification on these criteria was subjective and it is not known whether good gloves were discarded or bad gloves were accepted.

Delamination, often on the fingers, but sometimes on the palms was common. Some of this was probably due to a mismatch between the elasticity of the support fabric and that of the the polymer coating, coupled with poor bonding between the support fabric and the polymer. Shearing forces by tasks produced the delamination. Coatings like urethane bond well, but have poor chemical resistance. It is difficult to produce good adhesion with nitrile polymers.

Most tasks and tools often assume right- handedness, and as most workers are right handed, there is an excess of good left handed gloves in most batches. Good gloves of the excess hand are discarded to balance numbers.

The face of fingers, fingertips and palm were all locations for failure and it seemed that this related to direct damage to the gloves. The trials differentiated "old" from "worn" gloves as some gloves were quite new, but generally worn out. There were a few gloves where the plasticiser had leached out or had hardened residue ("hard") and few with chemical damage, breakdown of the polymer coating, or “heat burns”. It is believed that in most cases the heat damage was from placing the gloves on a hot surface.

Around 6% of gloves appeared to be damaged by the laundering process. This sort of damage is minimised by optimising pH, temperature and other laundering parameters.

4.2. Glove sorting

Avoiding recycling bad gloves and discarding good gloves is the aim of the human sorting process, so an examination of the how the sorters performed was of interest. Even batches of new gloves include ones with defects, so acceptability is really a matter of degree of classification error rather than being 100% right. Unfortunately, it is not yet possible to determine in absolute terms the accuracy of the sorter, on the reproducibility of the process for a particular sorter.

Sorter 1 was very experienced and consistently gave the same results. Sorter 2 was younger and less experienced, but rejected more gloves and may have been more influenced by the presence of the observer (LC).

Sorter 1 rejected the same number of gloves when the same batch was sorted on two days (18/19%) and rejected the same gloves 96% of the time. This consistency dropped for sorter 2 to 82%, and may indicate more training is required. Sorter 1 gave consistent reasons for rejection, but sorter 1 missed holes as the primary reason for failure 16% of the time. For these trials, only the primary reason for failure was recorded, but it is likely that if all reasons for failure were elicited, the consistency in classifying failures would have been better for the second sorter.

4.3. The need for a standard for laundered gloves and protective suits.

As the laundering process is refined and changes in protective properties with use are better understood, there will be an unmet need for performance specifications on the laundering process for gloves and chemical suits. A user needs to be able to specify:

- What level of residual contamination, both surface and matrix, is acceptable.
- What changes to barrier properties are acceptable. This can be indicated by chemical permeation resistance (Standards Australia 2005)
- What changes to physical properties are acceptable. This can include tensile strength, cut, tear and puncture resistance, and even thermal properties (for firefighters suits).
- What colour changes (fading, discolouration, staining) are acceptable. This is more important for suits where visibility of the suit is important.

Before these issues are codified, there is a need for sophisticated research to determine how visual appearance relates to the potential for toxic exposures. Once this is known, then guidelines or a standard could be developed to enable the safe service life of a glove or protective suit to be determined in the workplace. A deeper discussion of this issue is beyond the scope of this paper.

4.4. Applicability of the information

Initially, glove failure data could be used in three ways.

1. The information on how gloves fail can be used to improve glove selection to obtain better protection for workers and an economic approach to the selection of an appropriate glove.
2. The information on reproducibility of sorting gloves is being used to guide improvements to the sorting process.

3. The additional information from the ongoing research outlined above will be used with the glove failure information to determine the effects of laundering on glove performance and to produce improvements in both the laundering and sorting process. The ongoing research program will validate the visual sorting of gloves as a reliable method of determining the service life of a glove.

Those involved with the use of chemical protective clothing will be able to apply some of this information to better protect workers from chemicals and to reduce toxic landfill. For manufacturers, this information will be of use in producing better gloves.

5. CONCLUSIONS

Trials with industrial gloves have shown patterns in how gloves fail and it appears that failure relates mainly to glove design and the bonding of the nitrile polymer to the fabric.

Very consistent sorting can be obtained, but further research is needed to determine to what extent good gloves are discarded or bad gloves are recycled.

There is a huge scope for future research into how the appearance of gloves and chemical suits correlate with changes in their protective properties.

There is a real need for guidelines and standards both in the workplace and in laundering operations to determine the safe service life of gloves and chemical suits based on appearance.

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