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How gloves fail

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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 up as contaminated landfill).
A commercial glove-laundering operation has provided a unique opportunity to investigate how gloves fail in many industries. Over 1,000 polymer-dipped (or partially polymer-dipped) gloves from 10 manufacturers were examined, and it was found that 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.

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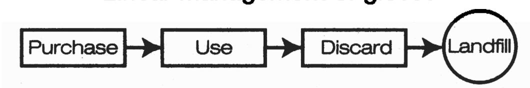
KEYWORDS

- PERSONAL PROTECTIVE EQUIPMENT
- GLOVES
- INDUSTRIAL USE
- MATERIAL FAILURE

Introduction

In the past, the usage cycle of industrial gloves has been linear (see Figure 1), with little opportunity to examine how gloves fail. Glove selection is commonly based on price rather than performance, and service life is often determined by smell or the obvious physical failure of the glove. Though the unit cost for new gloves can be low, they often fail to adequately protect the wearer as the initial selection was inappropriate for the task.

FIGURE 1
Linear management of gloves



The development of a commercial glove-laundering operation and management system (see Figure 2) by one of the authors (BJ) has meant that the selection of gloves which are more appropriate for the task can be made in a cost-effective manner. The management system supporting the laundering operation is complex, but it provides feedback to the client to enable better glove selection. Gloves are examined at various stages of the laundering cycle, so poor performance is readily apparent.

Good quality gloves can often be laundered many times with little obvious change, and they can replace gloves that have failed within minutes of use (that is, gloves that were purchased on price rather than performance). Recycling has been found to be viable, despite the costs of collecting the gloves and developing a proprietary laundering operation that is able to maximise the removal of visible contamination and minimise visible damage to the gloves.

The possibility of decontaminating gloves before reuse has been discussed by Perkins, and successive thermal decontaminations of glove swatches have been demonstrated by research at the National Institute for Occupational Safety and Health (US) to have a limited effect on chemical breakthrough times and permeation rates.[1-3] Other research on the laundering of gloves and suits has tended to focus on pesticide residues rather than barrier performance.[4-8]

There are numerous studies on the failure of disposable medical examination gloves and surgical gloves, but only one article indicated where industrial gloves fail.[9] These gloves 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 (see Figure 3).

Method

In this study, over 1,000 polymer-coated gloves (that had been sent from different workplaces for laundering and recycling, and had been rejected during the laundering process) were examined. The gloves were obtained from 23 employers in a range of light and heavy industries and local government across Queensland. The selection covered 12 glove manufacturers (Ansell, Atlas, Elliot, Elliott, Generic, Hercules, JWC, MSA, North, Pro Choice, Redback and Uvex). Some gloves were unbranded and these were recorded as a single "generic" manufacturer. There were 45 different models of glove. The coating polymers for 22 models were nitrile or foamed nitrile, six were latex, and seven were polyvinyl chloride (PVC). There was one model each of nylon/polyurethane, nylon/nitrile, and polyurethane. During the initial sorting of the gloves, those which were so heavily contaminated as to just spread the contamination through the washing machines were eliminated (see Figure 2). The remaining gloves were laundered, dried and sorted. The laundering method is proprietary, but the mechanical action, length of each cycle, pH and detergents all affect the laundering outcomes. Using the less-optimised laundering methods suggested by some glove manufacturers tended to result in more damage to the gloves, lower yields and shorter glove service life. This study focuses on the 921 post-laundered rejected gloves and how they failed.

Two experienced sorters were briefed on the trials and were able to identify why each glove that they rejected after laundering had failed. A classification scheme was developed to codify the reasons for glove failure (see Table 1). The sorters were interviewed regarding each glove to determine the primary reason for failure, and then asked if there were any other factors that would have led to rejection of the glove in the absence of the primary reason. This gave a more complete picture of the condition of the glove and reduced bias from picking the most likely reasons for rejection. Each glove was numbered and later photographed from the back and the front. The data were coded on an Excel spreadsheet which was set up to automatically generate histograms of glove failure during data entry.

TABLE 1
Modes of glove failure

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 (ie loss of plasticiser)
i	Damage to fingertip thumb
j	Damage to index finger tip
k	Damage to second finger tip
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 mutilated)

Note: codes g, s and v only apply to the pre-laundering sort.

To determine the consistency of the two sorters and the variation between them, a batch of 85 laundered gloves (both good and rejected) was sorted by both sorters on two consecutive days. In order to minimise bias in the results, care was taken not to give hints on which gloves had previously failed.

Results

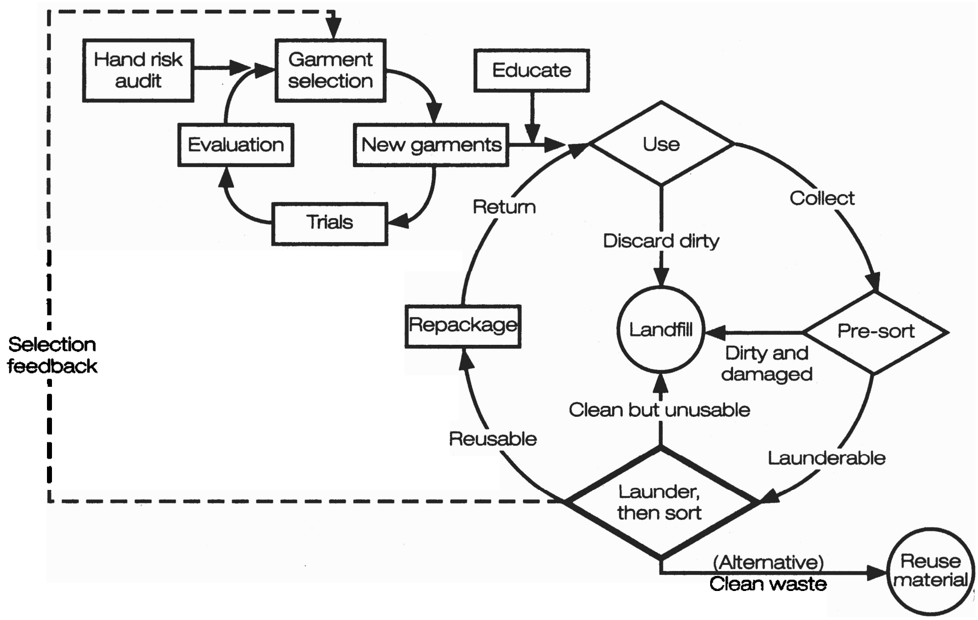
The overall pattern of failure was sorted in order of primary failure, and histograms of primary failure (black) and overall modes of failure (shaded) are shown in Figure 4. Even mutilated gloves (some with fingers cut off) were laundered, as the laundered glove could be sent to clean landfill.

Table 2 shows the level of consistency achieved by the two sorters when sorting the same batch of 85 gloves on two consecutive days (in the afternoon of the first day and in the morning of the next). 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. This inconsistency could result in the wearer of the laundered glove having direct chemical exposure through the penetration. Table 2 also shows the sorting outcomes for the 85 gloves (comparing the performance of the sorters on the two days and the differences between the two sorters).

TABLE 2
Sorter consistency (when sorting 85 gloves) on two consecutive days

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 one in four times	2	2
Sorter 1: "inconsistency" in reason for rejection	0	0
Sorter 2: "inconsistency" in reason for rejection	11	16

FIGURE 2
A new glove management system



Discussion

How and why gloves fail

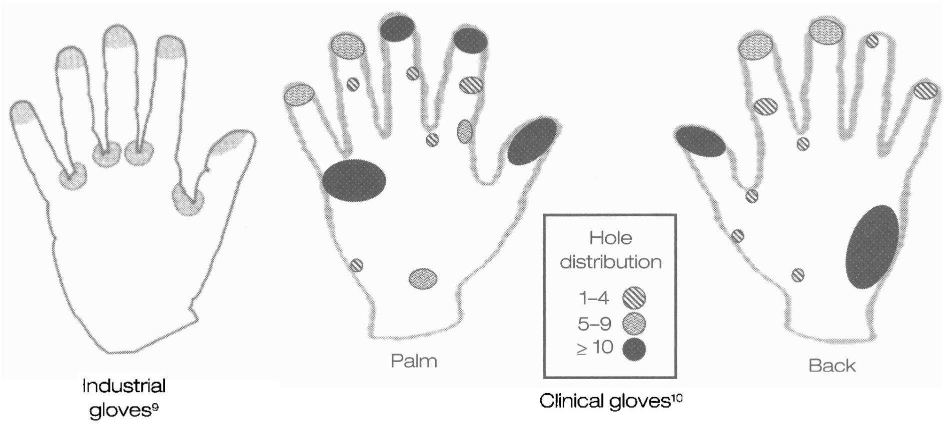
The most common primary mode of failure was a hole at the base of the thumb. This accounted for 404 failures (20.3%), once all reasons for failure had been analysed — though only 296 were picked up immediately (32.7% of primary failures). This tendency to select the base of the thumb first (when a glove also failed between fingers) is shown by the large number of gloves (33%) failing at the base of the thumb as the primary mode of failure. However, when all reasons of failure are considered, significant numbers of failures are seen to also occur between the other fingers. A typical failed glove is shown in Figure 5.

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. First, industrial gloves are less elastic than surgical gloves, so they tear more easily when stretched by movements of the fingers or thumb (particularly when the fabric is more elastic than the polymer coating). Second, the manufacturing process tends to produce seams and local thickening in these areas (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 made from an elasticised fabric. "Discoloured" meant that the glove was stained fairly uniformly, but did not show any residues. The cut-offs of acceptability of the laundered glove depended on the workplace to which the gloves were returned and was determined by the client. 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

FIGURE 3
Industrial and clinical glove failure locations



probably due to a mismatch of the elasticity of the support fabric and the polymer, coupled with poor bonding between the support fabric and the polymer. The shearing forces of some tasks may have produced the delamination. Coatings like urethane bond well, but have poor chemical resistance. It is difficult to produce good adhesion to fabrics with nitrile polymers.

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

The face of fingers, fingertips and the palm were all locations for failure and it seemed that this related to direct damage to the gloves. The trials differentiated "old" gloves from "worn" gloves, as some gloves were quite new, but they were often worn out. There were a few gloves where the plasticiser had leached out or had hardened residue ("hard"), and a 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 the gloves appeared to be damaged by the laundering process. This sort of damage is minimised by optimising pH, temperature and other laundering parameters.

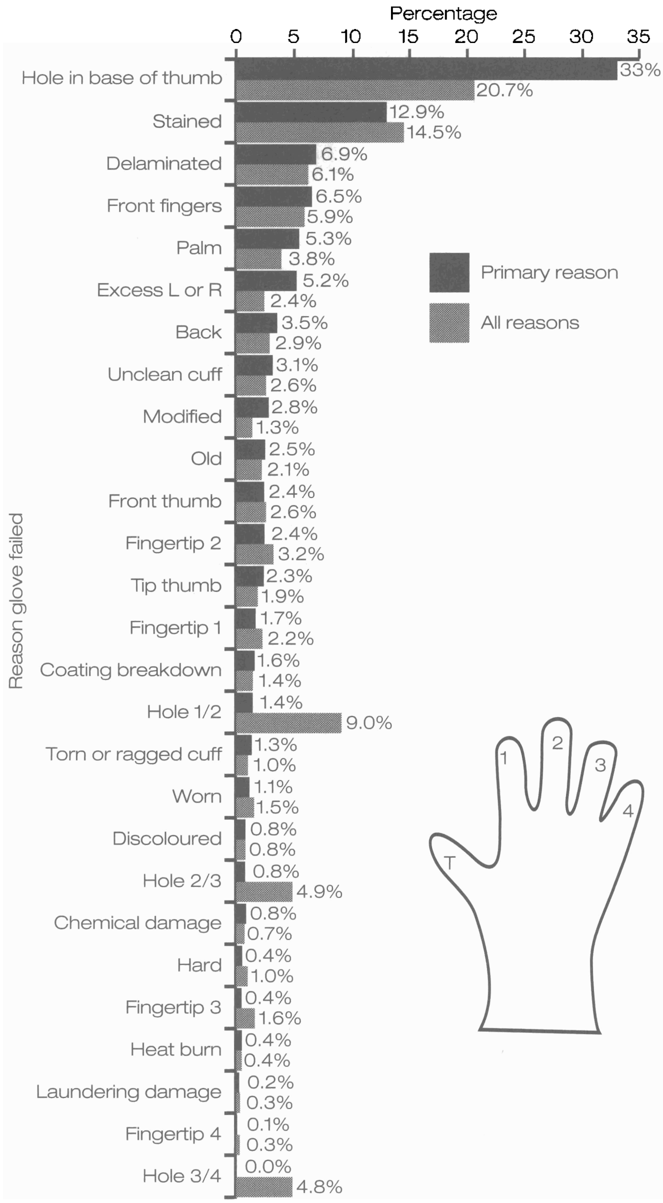
Glove sorting

Avoiding the recycling of bad gloves and the discarding of good gloves is the aim of the human sorting process, so an examination of 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, or the consistency of the process for a particular sorter.

Sorter 1 was very experienced and consistently gave the same results. 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.

Sorter 2 was younger and less experienced, but rejected more gloves and may have been more influenced by the presence of the observer (LC). The consistency dropped to 82% for Sorter 2, and this may indicate that more training is required. 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.

FIGURE 4
Failures in laundered gloves

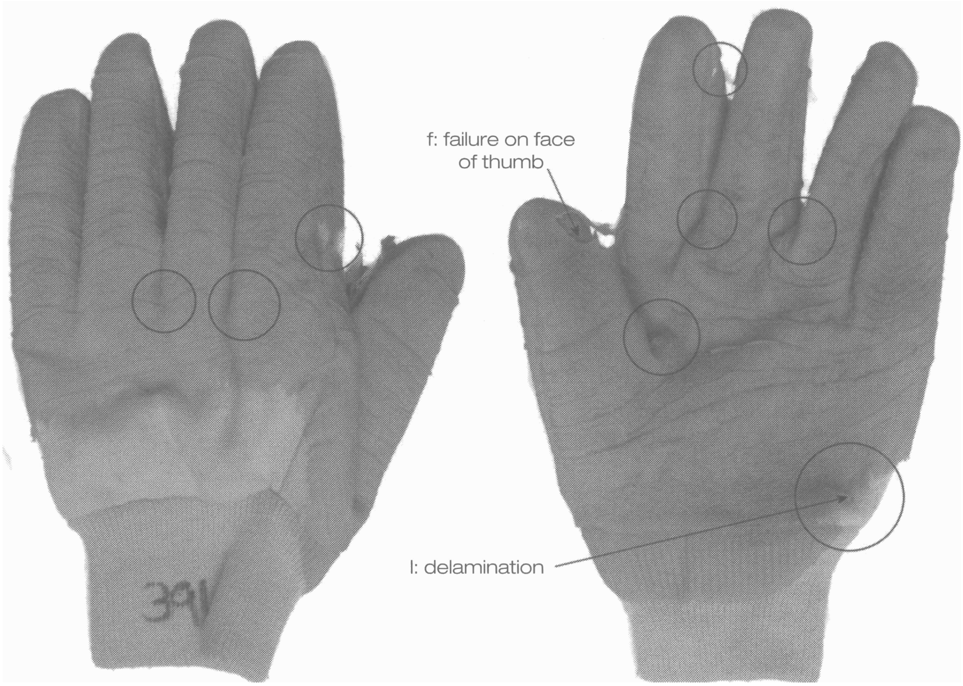


The need for a standard for laundered gloves and protective suits

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;

FIGURE 5
Example of glove failure (glove 391, a generic brand palm-dipped latex glove). Circles indicate locations of failures



— what changes to the barrier properties are acceptable. This can be indicated by chemical permeation resistance;[11]

— what changes to the physical properties are acceptable. This can include tensile strength, cut, tear and puncture resistance, and thermal properties (for firefighters' suits); and

— 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 complex research to be undertaken in order to determine how visual appearance relates to the potential for toxic exposures or injury. 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 more detailed discussion of this issue is beyond the scope of this paper.

Applicability of the information

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

1. the information on how gloves fail could be used to improve glove selection in order to provide better protection for workers and a more economical approach to the selection of appropriate gloves;
2. the information on consistency of sorting gloves could be used to guide improvements to the sorting process; and
3. the additional information from the ongoing research outlined above could be used with the glove failure information to determine what the effects of laundering are on glove performance and to improve both the laundering and the 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 the information from this study to better protect workers from chemicals and to reduce toxic landfill. For manufacturers, this information will be of use in producing better gloves.

Conclusion

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.

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

There is huge scope for future research into how the appearance of gloves and protective suits correlates with changes in their barrier properties. There is also a real need for guidelines and standards (both in the workplace and in laundering operations) to help to determine the safe service life of gloves and chemical suits based on appearance.

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