Figure 25 Typical set of equipment

Lifting lead for inspection

The skill is to be gentle; if possible two people should work together. Select sheets which are easily lifted, not obstructed by adjacent sheets, lightning conductor cables etc, and unlikely to be torn or otherwise damaged during lifting. Start by opening out the overcloak near the foot of the roll using the prising bar. Then try to lift it by prising up gently near the corner. Often one can then begin to lift the lead off the batten roll: check carefully whether it can be eased. If not, it may be better to try another sheet.

If the lead begins to lift at the bottom, support it there and try higher, aiming to loosen the whole length over the roll. If so, work up from the corner but take great care not to kink the lead over the roll. If kinking starts, ease back immediately and try to lever the lead away from the batten under the kink. Once the lead has begun to lift, check what is happening at the bottom (avoid kinks here too) and at the far side where the lifted sheet forms the undercloak: this may also need easing to permit free movement, particularly if there is a splashlap. Normally the corner can be lifted safely by between 200 and 300mm and propped in this position, to permit inspection and photography (see Figure 26).

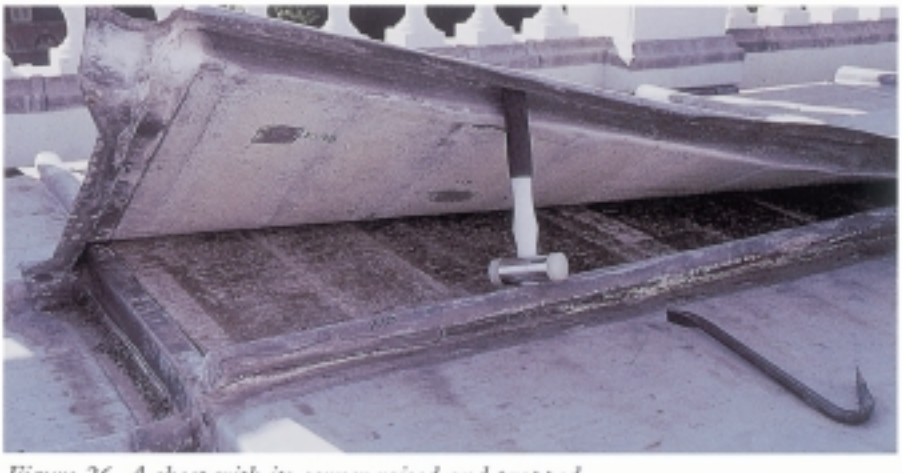

Figure 26 A sheet with its corner raised and propped

Replacing lead

Lead which has been lifted carefully can often be lowered gently back into position and worked down by firm hand and finally foot pressure. Be gentle: bossing too early can make it difficult to return the lead into place. When lowering, it is important that the upper sheet drops properly into the inside of the roll: sometimes the edge of the undercloak is bent upward when the sheet is lifted, and needs to be pushed back down first. Once the overcloak is nearly back into position, it will need final bossing-down to help the joints close reasonably.

DO NOT knock the outer edges back down first: instead work towards them from the inside of the roll and only tap them finally into place. Try to avoid bossing the lead into the base of the roll as this will make the sheet more difficult to remove on another occasion. It is often gentler not to hit the lead directly with the dresser, but to place the dresser in the required position and to tap it with a rubber hammer.

Safety precautions while working with lead

Lead and its corrosion products are hazardous to health and care must be taken not to ingest or inhale them. Wear a disposable dust mask and gloves which should be thrown away after each use, overalls which should be washed after each use. Always scrub your hands and wash your face thoroughly when work is finished and before handling or eating food. Sweep up any loose offcuts and corrosion products and dispose of them safely. To reduce fire risks, hot work is banned on many sites and subject to permits and agreed procedures on most others. Smoking is not allowable. For further safety information, see *Working with lead in construction: a guide to healthcare* LSA (1996).

Figure 27 Replacing the lead

Typical appearance of the lead

One may find the underside is

- ***Badly corroded*** (Figures 9 and 15) Major changes in detailing may be needed to isolate the lead from moisture and acids, including an additional layer of ventilated construction.

- ***Somewhat corroded*** (Figures 5, 14 and 21) Care must be taken to understand the situation and to check that alterations proposed are likely to make things better. The corrosion may be recent, or it may have occurred long ago. Tests are desirable to assess current conditions and to ensure that the proposals work in the manner intended.

- ***Showing little or no corrosion*** The lead may be either in bright, as-new condition (indicating that it has been very dry); or dulled (indicating that it has sometimes been damp, but that passivation has occurred). For roofs in good underside condition, past advice has been to renew as before, perhaps with some additional ventilation. However, if the old lead was passivated long in the past, or if the new lead was laid in adverse conditions (eg in the autumn, on wet or initially acid timbers, or on a damp building), ULC may occur. Small changes (eg in substrates, underlays, detailing or ventilation) may also be critical. Tests are therefore desirable.

Appearance of the corrosion product

ULC is usually white and predominantly the basic carbonate. Where organic acids are present ULC will also include acetate and/or formate. There may be some lead oxides: in reddish patches on their own, often in areas beneath the white corrosion product, sometimes giving the basic carbonate a yellow or pink tinge. Typically ULC is found in one of the following forms

- Thin powdery layers. These often indicate initial corrosion which is no longer active.

- Thin compact layers, which are difficult to scrape off. These tend to be protective but ultimately they may part company with the lead underneath, and corrosion will accelerate, forming additional layers.

- Thicker flaky or granular layers. These indicate more serious corrosion.

Distribution of ULC over a lead sheet

Occasionally a uniform layer of ULC covers the whole of the underside of a sheet. More often the distribution varies in relation to the location on the sheet, the pattern of the underlying deckings and underlays, local defects, and the history of moisture and acidity. Common patterns include

- Stripes of corrosion above the joints in the underlying boards, and opening out into the rolls in a 'fish-tail' pattern. This tends to occur in relatively dry situations where dew has formed before the lead has had a chance to build up its own passive coating.

- Stripes of corrosion as above, but spreading on to the boards from the gaps between them. This indicates a rather damper situation.

- Stripes of passivated (usually dark-coloured) lead above the gaps and in the fish-tails, and corrosion over the boards. This indicates a damp situation, with possible chemical activity over the boards.

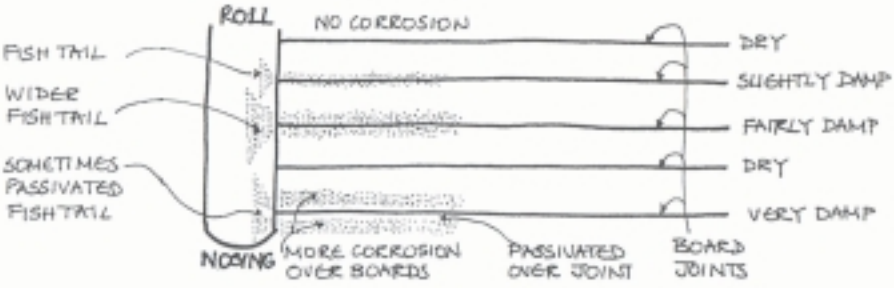

Figure 28 Characteristic variations in corrosion pattern over boards and gaps with changing moisture levels

Samples and tests

Samples of corrosion product

If significant amounts of ULC are found, it helps to have them analysed, particularly for formate and acetate content to indicate whether organic acids are involved: concentrations of over 50 parts per million (ppm) of acetate and 20ppm of formate in the substrate or the corrosion product are considered liable to put the lead at significant

risk. These levels will be detectable only in professional analytical laboratories. (The Lead Sheet Association can provide a list of contacts.)

Samples can be collected (taking appropriate precautions against contact, ingestion and inhalation) with a long-handled hooked scraper and put into a self-closing polythene sample bag. At least one gram of sample should be collected. Record carefully where it came from, both on the bag and in notes, using a unique sample code. To aid future identification, it helps to photograph the sample position. Samples of substrate are most easily taken by drilling a hole and collecting the drillings in a sample bag. Samples of the lead itself may also be required for investigations of composition and microstructures, but are not normally needed for ULC analysis.

Preparing for tests

Locations for specimen testing should include as wide as possible a range of conditions, and in particular

- any locations exhibiting evidence of some ULC in systematic patterns, eg above gaps, between boards
- uncorroded locations, to check that the environment is still inert
- in the centre of a bay and at the edge. Some samples (or cleaned areas) should be taken up into the area of the roll, particularly the inside where corrosion often occurs.
- over gaps and other weaknesses in the underlying decking

Testing specimens

Many tests can be made by wire-brushing patches of the existing lead to expose a clean surface, taking appropriate safety precautions. Alternatively, samples of new lead with pretreatments etc, as required, can be placed under the existing lead. Lift the lead, lay the samples (typically 150mm square, though they can be any size) where required (see above) and re-lay the existing lead as a weatherproof cap sheet, making sure it is in good mechanical and thermal contact with the samples underneath. Alternatively, the whole sheet can be replaced, with different parts of it treated as required.

Decking materials and underlays for in situ tests

Different substrates and underlays can be placed underneath the specimens - or specimen areas - as required. Remember that

- large specimen areas will normally be necessary to permit all conditions to be monitored.
- ideally, tests of impervious underlays require a complete bay, with the underlay sealed at all edges and extended under and beyond the roll battens. In the case of small samples, water vapour and acids can easily find their way around the edges.

Programming the tests

1 Ideally, samples should be first set up in May or June.

2 A further inspection in late September will then reveal if any corrosion or passivation has occurred during the summer. At this time, half the area of each sample (or one sample where pairs are being used) should be wire-brushed (and part re-coated, if coatings are being tested - see Section 6).

3 ULC is often most active in the autumn, and so the samples should be checked again in December.

4 Finally, in April, the two parts of each sample can be compared.

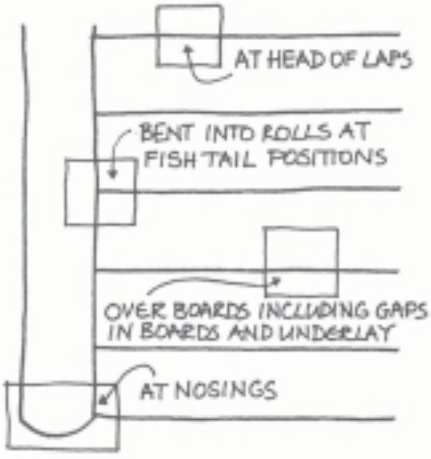

Figure 29 Typical corrosion sites and possible locations for test specimens or cleaned patches

If no specimens of a particular type are corroded then one can proceed with caution, though care will still need to be taken to keep the site dry during laying, and chalk coatings should be considered (see Appendix B). Otherwise, more thought will be required.

Caution

Anomalously good results may be obtained in years of exceptionally dry weather, as in 1995–97.

Appendix B

Chalk coating procedure

Ideally the lead should receive a pretreatment before or as soon as it arrives on site. This will help to stop it corroding if it gets wet when lying around. This should be followed by a final in situ treatment, after it has been formed into shape and just before it is finally laid. Stage 1 may be omitted in good, protected conditions where the lead can be kept dry until it is finally laid.

Stage 1: pretreatment

1.1 Remove any deposits from the lead sheets with a nylon scourer, to expose a bright and shiny surface.

1.2 Prepare a slurry of chalk powder in three times its volume of water. Stir regularly during application to ensure that the chalk remains in suspension.

1.3 Using a paintbrush or spray, apply a uniform coating of the slurry to the undersides of the lead sheets.

The slurry may also be applied to the top surface to help avoid initial corrosion.

1.4 Leave this for at least two hours, and preferably overnight. Then brush off any remaining chalk.

Stage 2: in situ treatment

2.1 Prepare a paste of chalk powder in twice its volume of water, to give a consistency similar to that of emulsion paint.

2.2 After bossing each lead sheet into shape, turn it over and paint on the paste to a sufficient thickness and uniformity that the surface of the lead can no longer be seen.

2.3 In order to avoid possible capillary attraction of rainwater, do not apply chalk to the bottom 50mm of a lap, the flat part of a splashlap, or the bottom 15mm of the adjacent step or roll (see Figure 31). Wipe off any chalk inadvertently applied to these areas.

2.4 If required, the chalk may also be applied to the substrate or underlay.

2.5 After a few minutes, when the chalk is touch-dry, lower the sheet carefully and fix in place.

Use of chalk-coated underlays

A chalk-coated underlay may also be beneficial (see Section 5). This can take various forms, including

- a thin coating of paste applied directly to the substrate boarding or to a building paper or similar underlay
- a chalk-impregnated geotextile underlay
- a 3mm skim coat of chalk paste applied to an underlay using plasterer's tools

Tests of alternative methods are currently in progress and their success is being evaluated. Chalk treatments and underlays are subject to a patent application. Alternative methods are currently being evaluated.

Some issues as yet unresolved

1 Chalk coating is subject to further development. Short-term tests are promising. Long-term performance is not yet known, both generally and in the event of damage to the protective layer. It appears that some 'healing' can occur if sufficient chalk is left in place.

2 Chalk left in place and on an underlay can provide initial protection against acetic acid. Since concentrations of organic acids often build up over time, it is not known how much long-term protection is afforded. In extended tests representing several years of adverse conditions, corrosion has sometimes been found (see also Section 4).

3 Precise details on application techniques have yet to be resolved. On windy days and on more steeply-pitched roofs, it can be difficult to get the chalk to

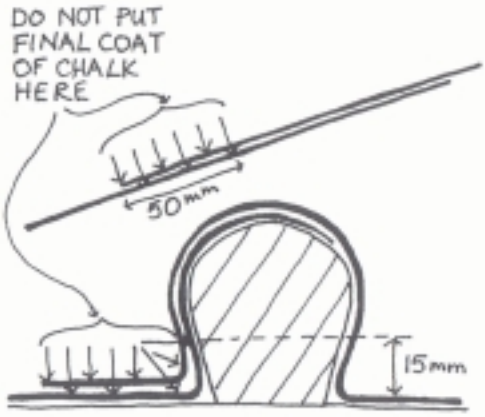

Figure 31 Do not put chalk at the very edges of the sheets. It could draw in moisture.

Figure 30 Applying the chalk slurry to the fresh lead. The coating thickness is sufficient when the surface of the lead can no longer be seen.

stay in place. Improved techniques would be desirable.

4 If water ingress or heavy condensation occurs, thick coatings of chalk may stick the lead to the base. This could be a particular problem when using a geotextile felt, where the fibre strands may reinforce the weak chalk and increase its tensile strength, and the risk of thermal fatigue failure.

5 Chalk paste which is left in place could draw in rainwater by capillary action. Residues should therefore not be left on the matching lead-to-lead surfaces in splashlaps, to the bottom 50mm of laps, or to the bottom 15mm vertical distance of rolls and steps.

6 A chalked environment might conceivably be more conducive to growth of moulds and fungi.

Safety precautions while working with lead

Lead and its corrosion products are hazardous to health and care must be taken not to ingest or inhale them. Wear a disposable dust mask and gloves which should be thrown away after each use, overalls which should be washed after each use. Always scrub your hands and wash your face thoroughly when work is finished and before handling or eating food. Sweep up any loose offcuts and corrosion products and dispose of them safely. To reduce fire risks, hot work is banned on many sites and subject to permits and agreed procedures on most others. Smoking is not allowable. For further safety information, see *Working with lead in construction: a guide to healthcare* LSA (1996).

Glossary

Aggressive Chemicals or environments likely to cause lead to corrode

Batten roll A roll formed over a timber batten

Bossing Beating the lead into shape using a dresser

Breather layer A membrane of paper or synthetic material which is permeable to air and water vapour but not to liquid water

Capillary action The process by which water rises into a thin gap owing to its surface tension

Code A reference for the thickness of lead sheet *Code 5:* 2.24mm *Code 6:* 2.65mm. *Code 7:* 3.15mm. *Code 8:* 3.55mm. Roofs in historic buildings usually use *Codes 7, 8* or thicker. Thinner Codes are used for flashings.

Dew point The temperature at which dew first begins to form on a cooled surface. A useful measure of the moisture content of a body of moist air and the likelihood of condensation.

Dresser A wooden or hard plastic tool used to boss lead into shape

Direct machine-cast (DM) lead Lead sheet prepared by pouring molten lead over a water-cooled drum

Geotextile A fleece of synthetic fibres typically 3mm thick developed for soil stabilisation, filtration etc, but also used as an underlay for lead

Hollow roll A roll formed around a hollow core

Inodorous felt A roofing felt based on flax fibres with resin binders used as an underlay to roofs covered with flexible metal sheet

Milled lead Lead sheet prepared by passing a billet between steel rollers

Overcloak / undercloak The upper / lower sheet of lead at a roll or lap

Passivation The development on a metal surface of a protective patina which provides some resistance to corrosion.

Patination oil A site-applied coating which protects new lead while it develops a protective patina. This avoids the initial corrosion and white run-off which may sometimes be caused by early rain or dew.

Roll A raised semicircular joint between two lead sheets

Sand-cast lead Lead sheet prepared by flowing molten lead out over a sand bed

Splashlap An extension of the free edge of the over-cloak for typically 40-50mm beyond a roll or step in order to provide additional strength and weather resistance

Thermal pumping A process by which moisture can be drawn into (or expelled from) a cavity by the cyclic expansion and contraction of the air trapped within it as the temperature changes

Bibliography

LSA, 1990, 1992 and 1993 *The lead sheet manual*, Vols 1, 2 and 3, The Lead Sheet Association, Tunbridge Wells

—, 1996 *Working with lead in construction: a guide to healthcare*, Lead Sheet Association, Tunbridge Wells

EASA, 1986 Consultation Document, *Corrosion of lead roofing: interim report of a sub-committee*, Ecclesiastical Architects' and Surveyors' Association

LDA, 1988 Condensation - a problem ..... even for lead, *Lead Development Association Bulletin*, 5, 11

Bordass, W, 1996 Underside lead corrosion, in J M Teutonico (ed), *A future for the past*, 81-98, English Heritage/James and James, London

—, in press, 1997 The underside corrosion of lead roofs and its prevention, *English Heritage Research Transactions*, 1, English Heritage/James and James, London

BRE, 1994 *Thermal insulation: avoiding risks*, 2 edn, Building Research Establishment, Garston

—, 1985 *Corrosion of metals by wood*, Building Research Establishment Digest 301, Garston

DoI, 1979 *Corrosion of metals by wood*, Department of Industry, London

Hoffmann, W, 1970 *Lead as a corrosion-resistant material*, Chapter 5 in *Lead and lead alloys*, Springer Verlag, Hamburg

Useful addresses

(current at time of going to press)

Lead Sheet Association
St John's Road, Tunbridge Wells
Kent TN4 9XA Tel 07000 656463

Lead Contractors Association
(Address as for Lead Sheet Association)
Tel 01892 513737

Acknowledgements

This leaflet was written by William Bordass Associates with Rowan Technologies Ltd and the Architectural Conservation Team at English Heritage. It is based on research carried out by William Bordass Associates and Rowan Technologies Ltd. The line drawings were by Joanna Eley.

English Heritage and the Lead Sheet Association are grateful for the help and advice received from the following: the Interface Analysis Centre at Bristol University (where research students were co-sponsored by the Engineering and Physical Sciences Research Council and the National Trust), the Building Research Establishment (Scottish Laboratory), and the Lead Sheet Association's Technical Committee members. Particular thanks are given to Dr Rob Edwards of John Moores University, Liverpool, who carried out the analysis of corrosion samples.

The Historic Royal Palaces Agency made a significant financial contribution to the project which facilitated comprehensive monitoring and testing. Thanks are also given to all the owners of and advisers to the thirty buildings investigated during the study, and in particular to the National Trust.

The chalk used in the research (grades SF100 or SF200) was obtained from Needham Chalks Ltd. The Lead Sheet Association may be able to advise on local suppliers.

ENGLISH HERITAGE

English Heritage, 23 Savile Row, London W1X 1AB 0171 973 3434

© English Heritage 1997 Product code XH20055 April 1997