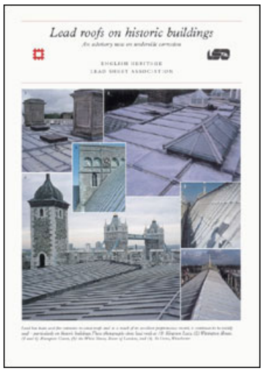
Historic England

Lead roofs on historic buildings



On 1st April 2015 the Historic Buildings and Monuments Commission for England changed its common name from English Heritage to Historic England. We are now re-branding all our documents.

Although this document refers to English Heritage, it is still the Commission's current advice and guidance and will in due course be re-branded as Historic England.

Please see our website for up to date contact information, and further advice.

We welcome feedback to help improve this document, which will be periodically revised. Please email comments to guidance@HistoricEngland.org.uk it has not been possible to verify this in laboratory tests.

- Deckings of sheet materials isolate the underside of the lead from the roofspace environment, so condensation does not immediately occur. However, if condensate builds up or water ingress occurs, the trapped moisture frequently causes damage, particularly because the organic acids which are often present in timber panel products also accumulate. Plywood can also trap water in its inner layers even when its surfaces are apparently dry.

As a general rule, in dry conditions both continuous and gapped substrates can perform satisfactorily (but avoid risky timbers - see below and refer to Section 5 on underlays). In damper conditions, both are susceptible to corrosion but trapped moisture and acids tend to create more severe problems above continuous substrates than condensation does with gapped substrates. However, the detailed performance in gapped situations is complex and corrosion varies.

Acidity in timbers

As discussed in Section 2, all timbers contain acids which can build up to harmful concentrations and attack lead. Even when dry, vapours from some species - notoriously but by no means exclusively oak - can attack metals, as noted below [source: *Corrosion of metals by wood* (separate publications by DoI 1979 and BRE 1985)]. This list is not exhaustive.

Severe risk Oak, Sweet chestnut

High risk Beech, Birch, Douglas fir, Gaboon, Teak, Western red cedar

Moderate risk Parana pine, Spruce, Elm, African mahogany, Walnut, Iroko, Ramin, Obeche

While no timber product is completely free of risk, in practice standard white softwood (usually Baltic whitewood) appears to be as satisfactory as any. Wood-based panel products are usually more corrosive than their constituent species: processing often causes hydrolysis and introduces formic acid. Whilst details vary with type, manufacturer and batch, in the absence of other evidence they should all be regarded as *severe*. They should never be used in potentially damp situations.

Assessing existing deckings

Reviewing suitability

Deckings seldom decay unless they have been subject to gross condensation or water accumulation. Insects and fungi cannot easily flourish in the wide range of temperatures and moisture levels that changing weather imposes on deckings. One can therefore often retain existing deckings, particularly if they are sound softwood, low in acid content.

However, aggressive species - particularly oak (even if old) and manufactured boards - may still be a hazard. If there is already ULC, the corrosion product and the timber should be tested for the presence of acetate and formate, and great care should be taken if levels are above 50ppm and 20ppm (parts per million) respectively. Even if not, these timbers may still attack fresh lead: tests and precautionary measures are desirable (see Section 6 and Appendices A and B).

What if the decking is aggressive?

Replacement or protection may be necessary. In any replacement, consider the guidelines in the box below and if possible test the proposed solution in small areas (see Appendix A). For protection, impervious separating underlays have often been used. However in practice their performance sometimes causes problems, as discussed in Section 5.

If it is essential to retain certain timbers in spite of their aggressiveness to lead, then chalk and other coatings may provide useful protection from initial corrosion (see Section 6 and Appendix B). However, given the

Checking timbers for acidity

Even if decking timbers are chosen from species not known for high corrosion risk, initial acidity will vary with provenance and processing. In cases of uncertainty, initial pH (acidity) tests can be helpful. Most laboratories will be able to do this easily. (The Lead Sheet Association can provide a list of contacts.) The procedure is as follows

Select a clean, sharp drill bit (typically 10mm in diameter)

Drill out samples of wood from several positions in each batch

Wipe clean the drill on a dry paper towel after each drilling

Place each set of drillings in a sample bag and label it

In the laboratory, weigh out 0.5 grams of drillings

Place in a test tube with 50ml of pure deionised water

Cap, shake, leave overnight and shake again

Measure pH with an electronic meter or a chemical indicator

Compare samples of each batch for consistency

Take additional samples if the spread is large

Reject timbers with an average pH consistently less than 5.5. (The lower the pH, the higher the acidity.)

cumulative effect, this protection may not last indefinitely. For complete isolation, it would be necessary to form a VWR (see Sections 1 and 3) by placing a long-lived AVCL over the aggressive boarding, insulation above that as required and an externally-ventilated airspace over that. While this might seem radical, maintenance records suggest that some roofs now subject to severe ULC may also have required frequent attention in the past: over seasoned oak lifetimes of some 40 years are typical. More detailed historical research on lifecycles is now in progress.

Concrete and mortar substrates

Fresh concrete, mortar and lime are aggressive to lead, and contact should be avoided, particularly where there is any likelihood of dampness and condensation. In marginal situations, a bitumen-cored building paper underlay is often used to provide some protection. Conversely, carbonated mortars and concrete can themselves have a protective effect.

Selection and use of new deckings

Where new decking timbers are used in replacements or repairs, the research indicates

- Choose a wood known to have a low corrosion risk, typically whitewood. Avoid all species listed in *Acidity in timbers* (p13). Use manufactured boards with great care, and only where moisture cannot be a problem.

- Protect the work from the elements and keep the substrate timbers dry. Where timbers have an initial moisture content above 16%, lead pretreatment is desirable. See Section 6.

- Seek to avoid timber preservatives in deckings and roll battens: the wood often arrives damp; preservative salts absorb moisture from the air and are electrolytes which can increase corrosion. The solvents in solvent-borne preservatives (now increasingly rarely used) may also inhibit passivation: they should be allowed to evaporate for several weeks with the boards stacked so that each is well-ventilated.

- Ideally, check the acidity of samples: the lower the pH, the more acid. (See box *Checking timbers for acidity.*) NB: this is an additional test for benign species: even high risk species do not always have a low initial pH - their acidity can develop over time.

5 Underlays and their performance

Purpose and function

Underlays are often put under the lead, in order to

- promote free movement, reducing thermal stresses and fatigue

- hold back moisture or condensation

- provide an even base for the lead

- isolate the lead from acid deckings, such as oak and plywood

- isolate the lead from fresh concrete or mortar, which are alkaline.

Underlays can also be useful carriers for protective chemicals (see Section 6).

Is an underlay necessary?

In many historic buildings the lead rests directly on planed or rough-sawn boarding. On sawn, non-resinous timbers of non-aggressive softwoods, this can work well, particularly on relatively dry, steeply-pitched gap-boarded roofs. On lower-pitched roofs, it is normal to find at least some corrosion. There can also be problems where the wood is resinous (when it may stick the lead down in places), acid (where it may attack the lead), or on low-pitched roofs (where the lead is not free to move, it is more likely to buckle as it expands or stretch as it contracts).

Comparative performance of underlays

Impermeable underlays

Impermeable materials such as roofing felt and polymers can potentially shield lead from moisture and chemicals originating inside the building. However, if moisture from any source (condensation, ingress, or construction) becomes trapped between the underlay and the lead, it can do substantial damage by standing or distilling in a poorly-ventilated environment, particularly in the presence of organic acids. Condensation occurring beneath the underlay is also more likely to be

Figure 21 A typical corrosion pattern where lead has been laid directly over softwood boards in this historic house by the Thames, now used as offices. After 90 years, the underside of the lead is still in relatively good condition, but moisture and acids have caused some corrosion over the boards, while areas above the gaps are passivated. Note the heavier corrosion under the nosing, where trapped moisture is less readily able to disperse.

trapped because it has no route for outward escape; this can increase the risk of decay in the underlying timbers.

Warning

Bitumen-containing underlays can soften in the sun and stick the lead down, possibly causing failure by thermal stresses. Resin binders in inodorous felts have also sometimes had the same effect.

Building paper

In relatively dry conditions, the absorptive effect of a building paper surface in contact with the lead appears to be helpful. Modern synthetic breather materials do not have the same effect and in tests undertaken up to the time this leaflet went to press more corrosion has usually been found. The paper should be lapped by at least 200mm, and run across rather than down the slope. It must be taken under the rolls, with battens - if used - fixed down through it.
If the paper is dropped-in between the roll battens, water vapour, moist air and acids tend to emerge in a concentrated stream along the edges, causing local corrosion. In more aggressive conditions, moisture and acids finding their way through laps and even small holes can cause severe local corrosion, particularly at the perimeter of the bay or near gaps in the underlying decking, where fluctuations in conditions tend to be greatest and air and carbon dioxide have better access. Fungal attack and spread on building paper has been reported occasionally. Bitumen-cored building paper can occasionally exude bitumen, and adhere to the lead, particularly where the bitumen is leached out by resins from knots or by organic solvent carriers used in some preservatives and insecticides.

Permeable felts

Blanket-like materials of organic fibres (eg inodorous felt) or synthetic geotextiles can ventilate the underside of the lead, helping to bring in carbon dioxide and let out moisture. Conversely, however, when the air is moist, condensation will start more rapidly, leading to more initial corrosion on unprotected lead. More frequent condensation/evaporation cycles can also increase corrosion of unprotected lead, although passivated surfaces may withstand them.

Geotextiles tend not to absorb moisture while permitting relatively free passage of air and water vapour. Sometimes this can reduce the potentially beneficial buffering effects of contact with low-acid timber. In moist conditions the timber is also less able to protect the lead by absorbing moisture: and in sunny weather the chance of a self-passivating effect is also reduced. Hence more condensation corrosion is often found over fleeces than over softwood alone. The corrosion tends to be most marked above the gaps between the boards through which moist air emerges (as shown in Figure 8). Some geotextiles have strong capillarity, causing moisture to be retained and to travel long distances from a damp patch. Others encourage water to run off.

In relatively dry conditions, ULC tends to be less over organic fibres (which are less permeable to air and can also absorb some moisture) than over geotextiles. In damper or more aggressive conditions, however, the situation may reverse, since acids in particular can disperse more easily through the geotextiles, while the organic fibres can retain moisture and acid and may also decay.

Breather membranes

These can provide controlled access of air by diffusion through the membrane and controlled egress of trapped moisture if necessary, while restricting the bulk air movement which can cause rapid condensation over permeable felts. They are helpful in reducing the amount of transient overnight condensation but not for more prolonged dampness. New developments tend to be making these products increasingly permeable and hence less good at protecting the lead in this way.

Double-layer underlays

Condensation risk analysis suggests that a relatively permeable fleece over a relatively impermeable membrane could allow trapped moisture to escape relatively easily via the fleece and the joints in the lead. In practice, however, corrosion by ingressed moisture can be a problem, and small-scale tests have been disappointing. In addition, although the volume of air trapped in the fleece between the impermeable membrane and the lead is small, it could draw in moisture by thermal pumping as in the 'warm roof' (see Section 1).

Figure 22 At this church in Yorkshire, roofing felt was used to protect the lead from acid vapours from the oak ceiling/decking. Although much of the lead has been protected, local membrane failure together with some water ingress has led to localised corrosion which in places has perforated the lead sheet.

Conclusions on underlays

Most underlays have both good and bad effects, and the research to date has not been able to recommend any one approach unequivocally. Meanwhile

- in steeply-pitched roofs with roofspaces, where gap boarding is already used, an underlay may not be necessary. However, it is recommended that tests are carried out first (see Appendix A). Pretreatments may be desirable (see Section 6).
- in well-ventilated situations, such as VWRs, a plain building paper underlay can provide some protection from transient condensation, and assist passivation. Pretreatment may also be a useful precaution against minor shortcomings in design or execution.
- in reasonably dry conditions, and where pre-existing sheet materials such as plywood are present but are dry and do not appear to have caused problems, bitumen-cored building paper may be helpful, but it must be carefully laid, well-lapped and undamaged. It is particularly important that the butt joints between plywood sheets are well covered: it is here that water vapour and acids tend to emerge in the greatest quantities as the plywood is heated, particularly in the sun, sometimes causing severe local corrosion.
- with fleeces, severe long term corrosion may be reduced, but initial corrosion can sometimes be rapid. Where aggressive substrates such as oak are present, the fleece can provide some separation and absorb large amounts of chalk slurry as a protective layer.
- tests are currently being undertaken with coatings applied to the lead (see Section 6). Application of chalk paste to building papers, geotextiles and - directly - to suitable substrate boarding is also being studied.

6 Protective coatings

The nature of initial corrosion

Initial effects on lead can vary dramatically according to circumstances.

A If lead encounters water early in life - for example if it is laid on wet decking, a damp building, or in weather which subjects it to condensation - it can start to corrode rapidly. Once initiated, this corrosion tends to continue.

B In dry initial conditions, the lead may remain completely bright and unaffected. However, if conditions subsequently become damp, corrosion may start.

C In warm and slightly moist circumstances, passive layers may form spontaneously: they provide some initial protection from ULC when condensation does occur. The mechanism, described in Section 2, appears to have been an important contributor to the long life of some damp historic roofs.

Lead laid in the early summer is more likely to follow routes B or C and may be less susceptible to ULC. Conversely, lead laid in winter, and particularly in the dewy autumn months, will usually suffer some Type A initial corrosion, making it susceptible to further corrosion in adverse conditions. To avoid such largely uncontrollable variations and uncertainties, some initial protection to the lead is desirable.

Factory-applied coatings

Earlier research (EASA 1986) found that most suggested candidates could not survive handling and working on site. Recently, however, acrylic colour-coated lead flashings have come on the market which can survive a limited amount of bossing into shape: if necessary, these can be touched-in on site (important, because corrosion tends often to be worst at the edge of a damaged area). At present the products are not appropriate for most historic buildings, being available in narrow widths and thicknesses only, and usually coated on both sides. However, the future is promising.

Site treatments

The research has investigated treatments involving relatively simple, safe, readily-available materials suitable for use on site.

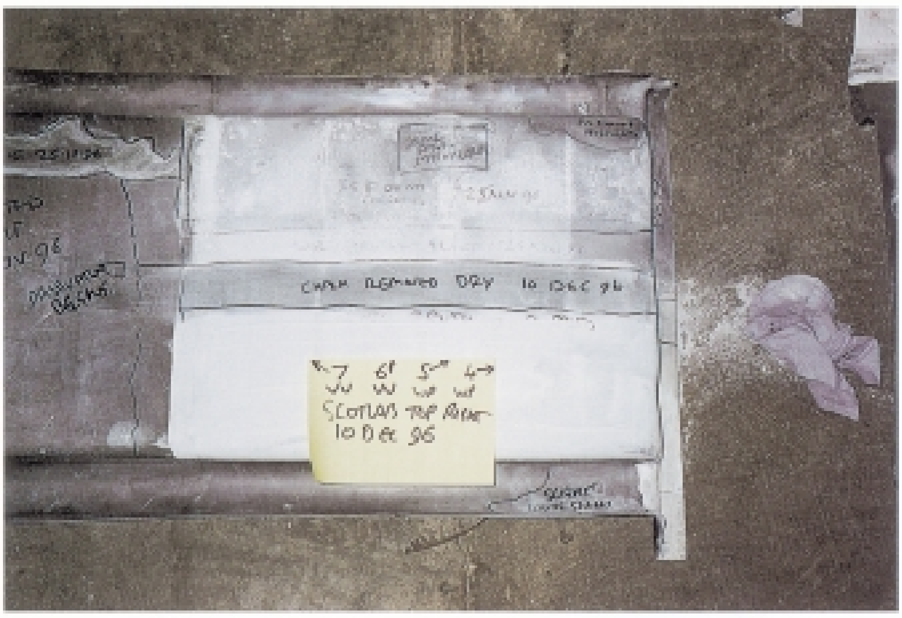


Figure 23 Tests at BRE Scottish Laboratory, which show the protective effect of chalk treatments. TOP: corroded after 2 and 4 weeks. BOTTOM: protected by chalk. MIDDLE: here the chalk has been brushed off to show a grey passivated surface beneath. Left of centre, a wisp of corrosion is appearing over the gap between the decking boards, which here were preservative-treated.

Water-repellent materials such as silicone oils, greases and sprays. These were disappointing on test rigs and in one-year site tests, though in the longer term a degree of protection was afforded.

Protective coatings such as linseed oil, patination oil and paint. These were relatively good, provided that they were applied after the lead had been shaped and given time to dry before the sheets were finally laid: this was usually difficult and slowed down the process. If not cured first, they were less effective and could also stick down the lead. Curing times vary with temperature and humidity, but are typically

- 24 hours for patination oil and paint (less in warm weather)
- several days for linseed oil

Fast-drying 2-part coatings would merit further investigation. In the past, linseed oil was used as a lubricant in some rolling mills, and some plumbers also routinely wiped lead with linseed oil, particularly after leadburning. On some sites this might incidentally have provided a certain amount of protection from ULC.

Pre-passivation Chemical methods were sought to create passive patinas similar to those obtained when the upper surface of a lead roof weathers for several months in the atmosphere. The chalk treatment described below was found to be most effective.

Treatments using chalk (calcium carbonate)

The simplest and most successful treatment studied in the laboratory was to apply a slurry of chalk powder in water to the lead. Limestone powder was also tried but soft chalk was better. The chalk assists initial passivation of the lead by controlling the pH of the water and providing a source of carbonate ions. The process is described in Appendix B. Further laboratory and site testing is in progress, with encouraging results to date.

Steps in the chalk coating process

A range of chalk treatment was tested on site and on a full-scale test rig. They included various combinations of an initial slurry coating when the lead first arrived on site, thicker paste coatings once the lead had been formed into shape and chalk-impregnated underlays. Preliminary findings were as follows.

- The initial slurry coating was the most important, as it provided some protection during sitework. The lead was visibly patinated after a few minutes at room temperature and had some resistance to initial corrosion.
- A second paste coating was desirable: this repaired any damaged areas and provided a reservoir of chalk to assist longer-term protection.
- Coated underlays were not sufficient in themselves: moisture could reach the lead and initiate ULC without activating the chalk. However, coated underlays prevented the chalk from falling away over gaps, etc. Extra chalk also gave some useful initial protection over acid substrates. However, in the long term it is likely that acids will ultimately accumulate to aggressive levels, but the lead's life might be usefully extended.

Site test results

In site tests up to the time of writing, the observed protection by chalk coatings and underlays was always good. The damper the roof, the better the protection tended to be: a useful property in protecting the lead from adverse starting conditions, for example over wet buildings and timbers, and from dewy nights. There is also the prospect of retaining some inappropriate decking materials of historic interest. However, application methods need to be improved, long-term tests have yet to be undertaken, and the general rule still applies that substrates should where possible be of low acidity and aggressiveness.

Suitable underlays for chalk

To date the best results have been obtained where chalk has been applied to the underside of the lead and the upper side of a plain reinforced building paper. Geotextile felts allow a thicker chalk layer to be used and are better at retaining it. However, in tests they have been less effective except in very damp or acid conditions. Here there is another possible problem: in very damp conditions, the chalk can stick to itself and to the lead. The bond is not strong, but the added reinforcement of geotextile could increase the risk of thermal fatigue cracking.

Contractors' experience with chalk coatings

Contractors vary in their acceptance of chalk coating: some have taken it in their stride, others find it a nuisance. The main problem is on steeply-pitched roofs where the chalk can fall off or blow off underlays such as building paper, particularly in windy conditions. Here a synthetic fibre scrim has helped to provide a 'key' but rucks in the scrim have been a problem on one site. Lifting the lead to apply the second coating before final fixing, always a nuisance, is also more difficult on steeply-pitched roofs, where temporary fixings may also have to be inserted and removed. A tough, quick-drying or factory-applied and easily retouched paint-like coating would clearly be more convenient.

Appendix A

Initial inspection, diagnosis and testing

Introduction

Whenever a lead roof is carefully inspected, it will be worth determining if ULC is present, and if it merits attention. However, it is not unusual to find some; it is seldom serious, and chalk treatment (Appendix B) may at first sight resemble ULC. If significant ULC is found, one should review whether it is serious, how it might have originated, and how it might be controlled. Before re-roofing, some tests are desirable even if there is little or no ULC, as new lead will not necessarily perform similarly.

Inspection from above

In extreme situations, evidence of holes, cracks, or repairs can be seen from above (see Figure 24). Piles of corrosion products - typically white flaky or granular material - can sometimes be found in gutters, or can fall out of rolls and laps when they are tapped. A badly-corroded roof may also have an uneven appearance and feel 'crunchy' underfoot, as layers of corrosion product are compressed. Incipient perforation is most readily visible when the roof is drying out after rain or dew: the failing areas will absorb some water and retain it for longer, giving them a darker appearance.

Figure 24 The large patches to the laps in the foreground suggest acid corrosion-related failures, which often first destroy the lead near the head of the lap. So do the smaller patches at the sides of the sheets, though similar damage can be caused by restrained thermal movement at tight fixing clips. The decking here is oak, probably 150–200 years old, but 35 years after re-leading, corrosion is severe.

Where is corrosion most commonly found?

This depends on the building, position and orientation. ULC commonly starts above gaps in the substrate boarding; at the perimeter of the sheet (on the inside of a roll; or in a lap or step, just above the top of the undercloak), or in a nosing. In general

- low-pitched roofs are more susceptible than steeply-pitched
- roofs with laps and splashlaps are more susceptible than roofs without
- very well-ventilated roofs (eg bell towers) are less afflicted
- roofs with roofspaces (ventilated or not) are less prone to corrosion than those without
- for those without roofspaces, high level roofs are more prone to corrosion than low level roofs

Checking elsewhere

If corrosion is found on one sheet, check similar parts of other sheets: there may be a regular, consistent pattern, at least over one area. However, patterns often change with location, pitch, and orientation, and are influenced by the underlying construction and environment.

Inspection under the lead

If ULC is suspected, try to look under the lead. This is most easily done in collaboration with a plumber, especially if there are hollow rolls or concealed clip fixings, which make opening-up and reinstatement a particularly skilled job. Where batten rolls are used, it is usually possible to lift at least the corner of a suitable sheet. Those who inspect lead roofs regularly may wish to take one of the short introductory courses in leadwork for specifiers that are run by the Lead Sheet Association (see Useful addresses, at end).

Equipment checklist

For those who wish to make their own inspections, useful equipment for lifting, recording and taking samples includes

- A steel prying bar, to help to lift the lead and remove nails
- A claw hammer, to help to lift, prop and to replace fixing nails
- A screwdriver, useful for prising apart and for testing timber soundness, as well as for removing screws
- Props to support the edge of the lead, once lifted. To avoid damaging the lead, avoid sharp points, edges or corners. A set of 25 x 50mm timber blocks between 150 and 300mm long with rounded arrises can be useful.
- A lead dresser, to replace the lead
- A mallet or rubber hammer for tapping the dresser
- A tape measure (This also helps to give a scale in photographs.)
- A torch
- A moisture meter, preferably with traditional resistance pins for local tests and non-intrusive electronic detection for scanning
- A camera with flash, preferably with zoom/macro lens
- A long-handled hooked paint scraper to collect samples
- Self-closing polythene sample bags
- Self-adhesive notes for identification in photographs
- A solvent-based permanent marker, for recording notes on the underside of the lead for later reminders, in photographs, and on sample bags. **CAUTION:** 'permanent' marking on the exposed side of the lead usually survives only a few months. It is best to locate positions in drawings and photographs.