TYPES AND CAUSES OF DETERIORATION

METALS: Typical metals encountered in outdoor objects are ferrous (iron and steels), cuprous (copper, bronze, brass) and aluminium alloys.

Ferrous metals

Include wrought iron, cast iron, steels and stainless steels. Wrought iron is an iron alloy with very low carbon content. Wrought iron contains fibrous inclusions caused by the integration of slag during the manufacturing process. This is what gives it a "grain" resembling wood, which is visible when it has corroded or broken. Historically, it was known as "commercially pure iron", however it no longer qualifies because current standards for commercially pure iron require a carbon content of less than 0.008% by weight. The carbon in wrought iron is generally not alloyed with the iron, but is mostly in the slag inclusions. Wrought iron is no longer commercially made, the last foundry producing it closed in 1973.

Steel is an alloy of iron and carbon, whereby between 0.07- 2.1 % carbon, by weight, is dissolved in the iron. Carbon and other elements act as a hardening agent. Varying the amount of alloying elements and form of their presence in the steel (solute elements, precipitated phase) controls qualities such as the hardness, ductility, and tensile strength of the resulting steel. Steel with increased carbon content can be made harder and stronger than iron, but is also less ductile.

Cast iron contains between 2.1 – 4% carbon and often contains between 1-3% silicon. The melting point of cast iron is about 300°C lower than pure iron. Cast iron is strong under compression, but not under tension. Cast iron tends to be more resistant to corrosion than wrought iron or steel.

Stainless steel is, by definition, a steel alloy with a minimum chromium content of 10.5% by weight. The chromium forms a passive surface layer of chromium oxides on the surface, which prevents corrosion. Depending on its designed use, stainless steels can also contain nickel, manganese, molybdenum, sulphur, phosphor, lead, aluminium, titanium, silicon, nitrogen and copper, plus others. Despite popular belief, stainless steel will corrode if it is in an environment that it is not designed for.

Ferrous metals are often plated to provide corrosion protection. Typical platings are zinc (galvanizing), tin (tinplate), lead (ternplate), chrome and nickel.

The main deterioration problem with ferrous metals is rust. Rust is caused by the oxidation of iron in the presence of moisture. Red/orange rust is chemically unstable, and porous, which allows moisture, oxygen, chlorides, sulphides and sulphates to rear bare metal, so a protective layer is not formed. Dark brown/black rust (typically magnetite) is usually chemically stable. When rust forms, it can also cause mechanical damage, because as it forms it occupies a larger volume than the metal, so in some situations it will cause parts to bend or even break.

Cuprous metals

Include copper, bronze (copper/tin alloys) brass (copper zinc alloys). Generally speaking, these alloys are fairly corrosion resistant. A protective layer of oxide is usually formed, giving them a dull, dark appearance. If exposed to organic acids, or moisture and carbon dioxide, pale green and/or blue copper carbonates may be formed. These are generally stable and are not an ongoing corrosion concern, although they may appear unsightly.

Sulphides cause tarnish, which on copper and its' alloys is typically a thin rainbow coloured patina. Copper sulphides are generally chemically stable.

Copper alloys are, however, vulnerable to active corrosion by chlorides. In the right conditions chlorides will result in pitting, and it is often referred to as "Bronze Disease" since it is possible for the corrosion to "infect" other nearby parts. Chloride corrosion of copper and its alloys is a cyclic process. The chlorides react with copper to form cupric chloride, which then in turn reacts with moisture to form hydrochloric acid, which then attacks un-corroded copper.

Copper alloys are also prone to reactions with some oils and fats to produce verdigris, a bright green waxy substance. This is saponification, or soap-making process. In the presence of moisture, copper reacts with oils to form copper oleates. It is often found where leather or oiled felts and timbers are in contact with copper. The corrosion is usually uniformly spread over the contact area, and pitting is rare. Once the verdigris is removed, the underlying metal will be bright – pink in the case of copper, and yellow in the case of bronze and brass.

Brass and bronze in conditions where they are subjected to mildly acid flowing water, are liable to de-alloying. This is known as "dezincification" and "destannification" respectively. The zinc and tin are gradually leached out of the alloys, leaving a porous, physically weak copper matrix.

Aluminium alloys

Can include copper, magnesium, zinc, silicone. Generally speaking, aluminium alloys have very good corrosion resistance, because of a thin layer of aluminium oxide that forms rapidly on the surface. Chlorides and sulphates are the most common causes of corrosion encountered. If the protective oxide layer is interrupted in the presence of chlorides, pitting usually results. Chloride pitting of aluminium is similar to bronze disease, in that it becomes a self-propagating cycle.

Some high strength wrought aluminium alloys are prone to stress corrosion. This often takes the appearance of rotting timber.

STONE, CERAMICS AND GLASS: The range of stone, ceramics and glass covers an enormous number of different types of materials. Generally speaking, the deterioration can be attributed to human interference, air pollution, salts and moisture, and biodeterioration.

Human interference is usually in the form of vandalism, such as graffiti or smashing of glass.

In the case of air pollution, sulphur oxides, nitrogen oxides and carbon dioxide can become dissolved in rain for form mildly acidic solutions which can etch some stones and glass. The damage is usually very slow, and can take decades for any appreciable effect to become noticeable. Similarly, airborne dust over a period of time can have an abrasive affect on stone, glass and ceramics.

Salts and moisture can do the most damage in the shortest time. Porous stones sitting on the ground can absorb dissolved salts through capillary action. When the moisture evaporates, the salt left behind crystallises and gradually breaks the structure of the stone.

Moisture by itself can have a detrimental effect on stone, ceramics and glass. In areas where temperatures fall to below 0^{o}C, moisture in cracks can freeze, expand and enlarge cracks. Moisture can also deposit minerals onto the surface, leaving crusts behind.

Biodeterioration is more common on stone than on ceramic or glass. It usually takes the form of mosses and lichens, and some larger plants such as ivy. The damage caused by these organisms may be physical or chemical. Physical damage results from the roots penetrating fissures in the stone and these swell and contract with changes in moisture or humidity.

Chemical damage results from organic acids produced by the organisms, which can slowly dissolve the stone.

WOOD, LEATHER & TEXTILES: These materials are deteriorated by biological attack, mechanical action, moisture, sunlight and weather cycles, and applied dressings (e.g. saddle soap).

Biological attack may be in the form of fungi, insect attack, rodent damage or birds.

Mechanical deterioration can be a result of use, such as leather straps and belts being flexed until they crack.

Changes in moisture content causes swelling and shrinking which results in cracks in timber.

Sunlight and weather cycles result in damage due to bleaching by sunlight, expansion and contraction due to temperature and moisture content changes, and freezing can cause cell structures to break with a subsequent loss of strength.

Applied dressings, such as saddle soap, are fine whilst the object is in service, because the object is usually cleaned and new dressing reapplied on a regular basis. Once this regular maintenance ceases, however, dressings often start to migrate to the surface where they form a sticky surface layer that attracts dust, etc. which in turn supports mould growth.

RUBBERS AND PLASTICS: covers an enormous range of materials.

Rubber is a very enigmatic material, in respect to its deterioration. Two apparently identical rubber components in the same environment can behave totally differently. One component may become brittle and cracked, whilst the other may become soft and sticky. Unlike most other materials, rubber tends not to be adversely affected by chlorides.

There are over 2 million different types of plastics. Plastics generally fall into two major classes - thermosets and thermoplastics.

Thermoset plastics are usually formed under heat and pressure in a mould, and once set, they cannot be re-melted to be reformed. Examples include phenol formaldehydes (Bakelite) urea formaldehyde, and some forms of polyurethane.

Thermoplastics may be formed under heat and pressure (e.g. polyethylene), or formed cold (e.g. nylon). The main characteristic of thermoplastics is that they can be remelted to be reformed.

Many materials are added to plastics. Plasticizers are used to counter brittleness and impart elasticity. Bulking agents and fillers are used to lower costs and to add strength. Stabilizers can be added to counter effects of UV light, to prevent fungal attack, or to reduce the rate of oxidation.

Probably the principal cause of deterioration of rubbers and plastics is sunlight. The various wavelengths of sunlight can cause different types of damage in different plastics. The two main types of damage are chain scissoring and cross-linking.

Chain scissoring occurs when enough energy is absorbed to break bonds in the polymer chains. This results in a weakening of the plastic. It is often observed as cracks or chalkiness of the surface.

Cross-linking occurs when absorbed energy promotes the formation of new bonds within the structure. Over time this can result in a plastic becoming insoluble in solvents that it was originally soluble in. It can also result in the plastic becoming less flexible and elastic.

Other types of deterioration include the loss of plasticizers, stress cracking through cyclic movements, and biological attack. Loss of plasticizers may be due to frequent washing action of water or solvents, or simply evaporation. The loss of plasticizers results in embrittlement and sometimes distortion, splitting and shrinkage.

Stress cracking through cyclic movements is often an indication that the plastic has passed its designed life. Plastic hinges are prime examples of this.

Biological attack is usually indirect. Most plastics have no nutritional value, but they are often contaminated with grease and dirt which can support fungal growth. The resultant organic acids produced by fungi can have a deleterious effect on the plastic. Plastics are sometimes attractive to rodents as gnawing posts.

TO WORK OR NOT TO WORK

To operate objects or not is an ongoing debate in the museum community. Both sides of the debate have their purists, and both have valid arguments. There is no single right or wrong answer. The right answer is the one that is right for your museum after due consideration is given to all arguments. More often than not, the decision will be largely influenced by available funding.

Arguments for operating machinery include a spectacle for visitors, movement, sound and smell which are part of the essence of the objects, a way of exercising systems and seals to aid in preservation, and a convenient way to move large heavy objects.

As a spectacle, few visitors wouldn't be impressed by the sight of a moving traction engine, and flying vintage aircraft always attract large crowds. The smell of a coal fired boiler, the hissing of steam and the clanking of metal parts, and the sweaty, grime covered faces of the operators add an entirely new dimension to a traction engine. They give the engine life. Without these things, many visitors may consider the traction engine to be little more than a boring large lump of metal.

Operating objects can be one way of preserving them. Many mechanical systems have seals in them that rely on being periodically wetted, either by lubricants or coolants, in order to remain in a swollen or flexible state to function properly. If these seals are left too long without immersion they can shrink and/or become brittle, which then leads to oil and coolant leaks. Operating engines also relieves stresses in springs, etc, and circulates oils which can prevent corrosion.

Maintaining large, heavy objects in operational condition can be a convenient if the object is required to be moved regularly. It can be very expensive to hire cranes to move such objects, and if they need to be moved frequently, the accumulated costs can out-weigh maintenance costs to keep it operational.

Arguments against operating large museum objects include costs, wear, sourcing replacements parts, loss of originality, and the risk of an accident damaging or even destroying the object or harming people.

The cost to operate a large object can be considerable. Consideration needs to be given to the purchase of suitable fuels and lubricants, spare parts, consumables, insurance, administrative costs including registrations, inspections and certifications, licences, etc, staff time to maintain and prepare for each event.

Operators need to be suitably qualified before they can legally operate many large objects, such as machines with boilers, army tanks, etc.

Boilers need to be inspected regularly and certified before they can be legally operated.

The operation of any object involves a certain amount of wear. In the life of an operating object there are three main stages of wear. The initial period of wear is when the object is new, and the rate of wear is usually high over a short operating time. This is usually termed the “running in” period, where parts rub against each other, wearing away the roughness caused during manufacture.

The second stage of wear is usually a low rate of wear over a long period of operating time. This often called the operational life. Most of the wear in this period occurs when the object is warming up to operating temperature. For large industrial machinery it may take as long as an hour or more for all parts to reach their operating temperature.

Towards the end of the operational life, wear starts to increase dramatically. This is the third stage, sometimes referred to as the breakdown stage. Parts are nearing the end of their design life and are often worn beyond acceptable tolerances. Continued operation of an object in this stage usually results in complete failure of one or more parts, sometimes catastrophically.

Replacement parts can be a problem for older machines. Some components can be refurbished, replicated or replaced with modern equivalents. Other parts, such as the glass vacuum valves in an old radio, are more difficult replace without significant redesign or reconfiguration. Every time a part is replaced some of the original material of the object is lost. At what point does it cease to be a real object and become a replica?

Health and Safety Issues must also be considered. Old machines can be dangerous. They are often in museums because they have been replaced by safer, more efficient machines made from safer, stronger materials (although this is not always the case, e.g. carbon fibre/epoxy technology are a hazard when they deteriorate). Most old vehicles have no power steering and un-boosted brakes, both of which can require considerable strength to operate. Few people today are accustomed to driving such vehicles. Some vehicles have nasty vices. For example, the Jeep from WW2 is notorious for tipping over when cornering, and the Ford V6 Capri was renowned for catching fire in the engine bay.

DISPLAY STANDS, MOUNTS AND SUPPORTS

Display stands & mounts are used to display an object in a particular attitude. Wherever possible, existing hard points should be used. Sometimes it may be convenient to remove certain parts so that the display stand can effectively support the object. Often, replica panels are necessary so that they can be cut and modified to allow displays stands to fit. The removed parts should be clearly labelled and recorded, and placed in storage for future reintegration with the object.

In the case where objects are displayed in such a fashion that people can walk under them, it is prudent to employ the services of a structural engineer to certify that both the object and the display stand are safe. Display stands and mounts should be discrete as possible, so as not to detract from the object they are supporting.

Supports are generally employed in storage to take the weight off vulnerable components or to raise them away from moisture, e.g. rubber tyres and wooden wheels, or they may be necessary to support disassembled object parts whilst they are being worked on. Supports tend to be less aesthetically pleasing, but more functional than display stands. They may be as simple as a few blocks of timber placed under an axle, or as complicated as a revolving support to allow an object to be rotated through 360^{o} to allow work to be carried out safely and comfortably. Nonetheless, as with display stands they should be placed at hard points, or be large enough to spread the load over a large area. As a general rule supports do not need certification by a structural engineer, because they are usually low.

TO COVER OR NOT TO COVER

Covering an outdoor object considerably reduces the rate of deterioration. A simple cover can prevent much moisture and particulate matter from landing on the object. It also reduces the amount of direct sunlight from reaching the object, which degrades surface coatings and organic material. This in turn reduces the amount of maintenance needed for the object. Covers can be as simple as a tarpaulin, or as elaborate as a dedicated structure or building.

Unfortunately, protective covers cost money, and they themselves need maintenance. A simple cover, such as a tarpaulin is relatively cheap in the short term, but it doesn't allow the object to be seen, and it will probably deteriorate to the point of needing replacement with five or six years. They are also prone to damage from the elements and vandalism, and if not drawn tight, they can damage the object underneath.

More effective covers can provide better protection, but may detract from the appearance of an object. A carport type of structure does allow an object to be seen and easily accessed, but they don't always look the best. Nonetheless, they do provide good protection from the elements and maintenance is not usually very difficult or expensive.

More elaborate and expensive enclosures can be purpose designed, and thus aesthetically complementary to the object. They can effectively isolate the object from the elements and the public. Needless to say, a large budget is usually required for such a structure. But even these types of structure can be detrimental to an object if not properly designed. Large glassed walls can result in high temperatures within the enclosure if orientated incorrectly. Enclosures can also keep the public at a distance from the object, which is not always ideal.

DOCUMENTATION

Planning is essential to the successful preservation of objects. It should be the first part of the process, and is often the lengthiest part. Planning should include the gathering of relevant historical information, identifying sources of material and parts, possible contractors, tools needed, estimates of materials and labour, projected timelines, and an idea of what the final product will look like.

The gathering of as much information as possible about the object is important. Items such as service history, manufacturers' records, manuals and instruction books, old photographs, schematic diagrams and production drawings are all very useful during the actual work stages of a restoration.

Identifying sources of materials and parts before work begins ensures that work is not interrupted through lack of these items. It may be found in the planning stages that certain parts or traditional materials are unavailable, and this can influence what work is or isn't carried out, or what modifications are necessary to achieve the desired outcome.

The identification of suitable contractors and their costs may affect budgets and schedules.

Budgets and projected timelines are essential. Projects without a developed budget often founder due to lack of funds. Long projects tend to founder as enthusiasm wanes, particularly amongst volunteers.

It is also essential to have an agreed idea of what the final product will look like. This helps to ensure that everyone is working towards the same outcome.

Documentation doesn't finish once the planning stage is completed. Reports to management, sponsors and stakeholders are often required. Also, ongoing treatment records should be generated for future use in both the short term and long term. Details such as the order of disassembly are inherently useful when it comes time to reassemble the object. During the disassembly process, discoveries are often made which may influence the course of the project, or provide interesting trivia about the object and the people who built it and used it. Handwriting is often found inside objects, put there by those who made them. Sometimes these may have been an aid to the worker; sometimes it may be historic graffiti. These should be documented and where possible, retained on the object.

It is important to document the condition of an object so that long term monitoring of wear and deterioration can be carried out. It is also important to keep thorough records of chemicals, techniques and treatments used, and why they were used. Documenting these provides a record for future custodians to determine what has worked and what hasn't, and can influence the choice of treatment options in the future. The documentation of chemicals used can also be important should workers have health problems at a later date.

Records should also be kept regarding what new parts/materials have been added to the object, and what modifications have been carried out, and why. This is important to remove any ambiguity about what is original and what is not, for future researchers.

Take lots of photographs, and annotate them for future reference.

MOVING LARGE OBJECTS

Plan your route, and take measurements. Whether it's across the car park or across the country, it's a good idea to go over the route first to check for obstacles on the ground, in the air and at the edges. Involve authorities if your move involves taking your large object off-site; it may be that road signs or power lines need to be removed or roads closed.

Always identify safe lifting points on an object. Sometimes this may involve inspection by an engineer to certify that an integral lifting point on an object is up to the task demanded of it. Always use the appropriate, certified lifting straps or chains. Safety of staff should be the priority.

If a single object is to be moved, then a dedicated support system is usually made. If a number of large objects are likely to be moved, then a modular system of interchangeable trolleys and bracing is a more efficient option.

Never let your pride get in the way of a successful object movement. Sometimes, it's just not your day and things won't move the way you want them to. If this is the case, be humble enough to stand aside and let someone else have try. Damaged pride is a lot easier to fix than a damaged object.

TREATMENT OPTIONS

There are five treatment approaches than can be adopted. These are preservation, conservation, restoration, maintenance and allowing degradation to occur.

Preservation involves minimal intervention to the object, and the goal is to preserve the object in its current state. This may be as simple as moving an object into better storage conditions, covering the object to protect it from the weather or may involve washing to remove deterioration causing material and coating with preservatives to arrest corrosion. Preservation doesn't always look attractive, but it should stop the condition of an object from getting worse until more interventive treatments can be carried out, if needed.

Conservation usually involves the stabilisation and retention of as much original material as possible, whilst still making the object presentable for display. New material is generally only added to ensure structural integrity. As much historical information in the object is retained as possible.

Restoration generally involves making changes to the object to make it more complete or operational, and in pristine condition. Original material is often replaced, and missing parts added for no other reason than to make the object look better and complete. It is not unusual for a project to involve both conservation and restoration aspects.

Maintenance should be a part of the above three options. Maintenance can reduce degradation until any of the above treatments can be carried out.

In some situations, cultural sensitivities may preclude the above options. Some objects are made for use at a single event, then allowed to return to the earth. In these situations, all you can realistically do is thoroughly document the object, and perhaps make some modifications to the local environment to slow down the degradation process. For example, drainage channels could be dug to divert groundwater.

TRADITIONAL MATERIALS VERSUS NEW MATERIALS: Careful consideration should be given to using modern materials rather than traditional materials. New materials are not always better than traditional materials, although they may be more readily available and cheaper. They often look different, which may or may not be an issue. Sometimes modern materials are more chemically stable and have a longer life than traditional materials, and sometimes they don't.

For example, fabric covered aircraft were originally covered with cotton or linen and tautened with cellulose nitrate dope. On modern fabric covered aircraft, synthetic fabrics are used with cellulose butyrate dope. The synthetic fabrics are lighter, stronger and finer than cotton and linen, and the butyrate dope is much less flammable than nitrate dope. From an aviation point of view, the synthetic fabrics and modern dopes are far superior to their older counterparts.

The problem from a museological point of view is that the synthetic fabrics, due to their finer fibres and weave don't look the same as cotton and linen, and in the case of the dopes, the butyrate dopes keep contracting as they age, whereas the contraction of nitrate dopes ceases once the solvents have evaporated. This is not a problem for a flying aircraft, because the fabric covering is replaced ever 5 years or so for safety reasons. An aircraft in a museum can be expected to retain its' fabric for over 50 years or more. The Australian War Memorial (AWM) had two of its' World War One German aircraft recoated with butyrate doped cotton fabric in the early 1970's. By the late 1990's it was apparent that the butyrate dope had continued to contract to the point where the fabric was ripping itself apart, and some of the smaller, more delicate timber parts in the wings were being crushed. The AWM's SE5a aircraft, with linen fabric and nitrate dope applied in the early 1930's does not yet need recovering.

Conversely, many modern materials are far better than their traditional counterparts. For example, the original type of brake fluids are hydroscopic, which means they absorb moisture which can lead to corrosion in the brake system. In a vehicle that is operated regularly, this is not necessarily a problem, because constant use heats the brake fluid causing the moisture to evaporate, and regular servicing would include periodically replacing the brake fluid. Some modern brake fluids are silicone based, which do not absorb moisture at all, so they can effectively be left in a brake system for much longer, without the risk of corrosion.

COLLABORATIVE APPROACHES TO TREATMENT: Finding the right people to work on a project can be crucial to success or failure. At the beginning of a project, the expertise needed should be identified. Engineers with the right type of experience, craftsman such as blacksmiths, wheelwrights and fitters, sheet-metal workers, machine-makers may all be needed. You may be lucky to find such people who are retired and willing to work as a volunteer, or you may have to pay for their expertise.

Volunteers are often crucial to the completion of a project. Often they will undertake more of the work than paid employees. They can be a very valuable asset, but they can also cause a lot of damage in a short period of time if they are not properly supervised. Their rights and responsibilities should be made clear at the beginning of a project. Many large museums require volunteers to sign contracts which stipulate the rights and responsibilities of both parties.

Finding other people or organisations doing the same type or similar work can have many benefits. It's usually cheaper to get two parts made than one. Others may have developed solutions to problems that you currently face and by sharing experiences, tips and techniques many problems can be avoided. If other groups know what you are doing, they can be on the lookout for the parts that you need, or they may be able to trade spare parts with you.

PUBLICITY: Never underestimate the value of publicity during a restoration. The local media is always on the lookout for local interest stories. The public are interested in hearing about old things being restored, and it is surprising what spare parts people have in their sheds, or original photographs and documents in the attic. More often than not, they are willing to donate these things to your cause.