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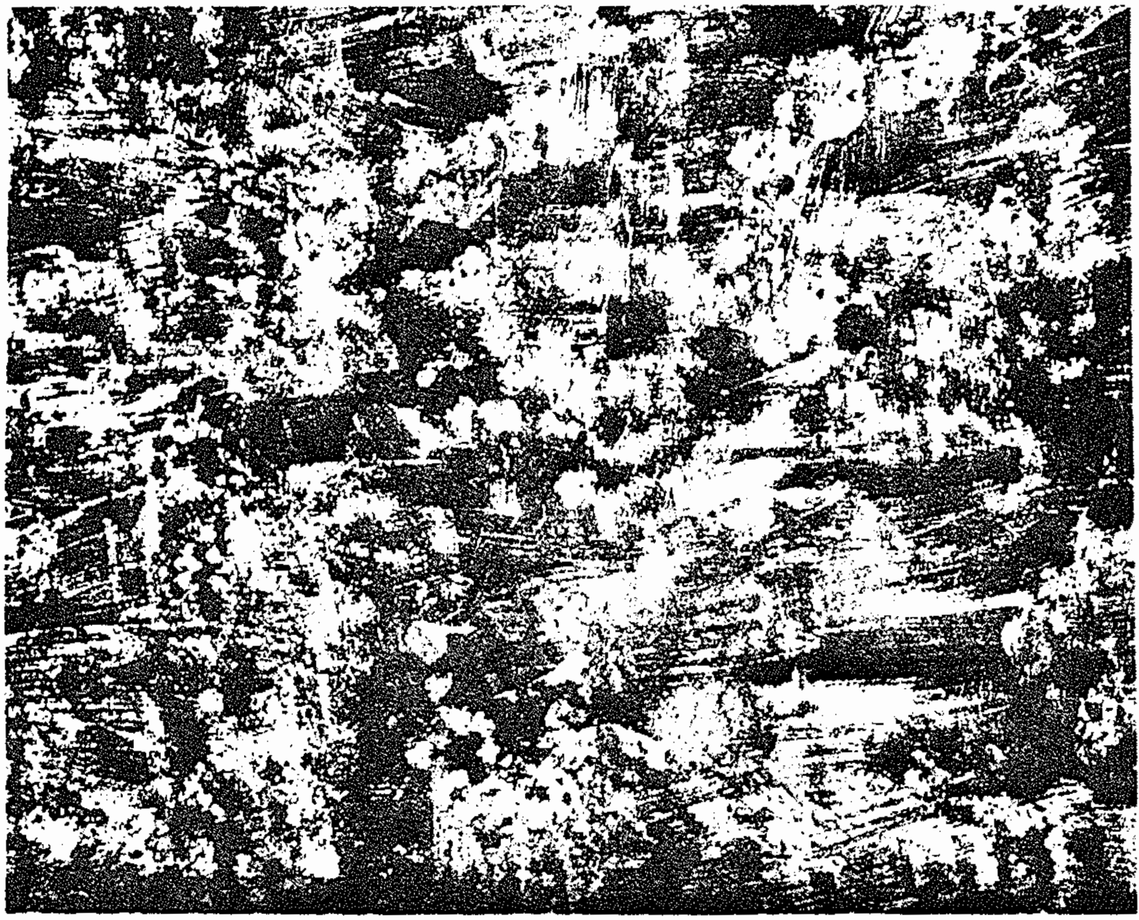
Corrosion of Air Tankers by Fire Retardants

By James B. Davis and Clinton B. Phillips



A Report for

California Air Attack Coordinating Committee

1965

THE CALIFORNIA AIR ATTACK COORDINATING COMMITTEE

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FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
Pacific Southwest Forest and Range Experiment Station
Equipment Development Center
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Contents

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Corrosion of Air Tankers by Fire Retardants[1]

Are fire retardant chemicals corrosive to air tankers? "Yes, but . . ." was the answer reached by a six-man task force[2] that examined 26 air tankers in California after the 1964 fire season. We found serious corrosion damage which had occurred during only one summer, to the tank and gates of one air tanker. But we also found another air tanker that showed no visible signs of corrosion damage after having been used for eight fire seasons. Between these two extremes, the 26 air tankers and 4 non-air tanker aircraft that were inspected showed considerable variance in extent of corrosion damage.

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[1] The authors received technical guidance from many sources, but are especially grateful to Charles B. Kendrick Jr., research metallurgist, and Richard F. Stratfull, corrosion chemist, both in the Structural Materials Section, California State Division of Highways, Sacramento; and to Leo V. Steck, formerly with Shell Chemical Company and now a technical advisor to the Pacific Southwest Forest and Range Experiment Station.

[2] The task force consisted of: Robert P. Langguth, senior research group leader, Inorganic Chemicals Division, Monsanto Co., St. Louis, Mo.; Ken Nelson, chemist, Arizona Agrochemical Co., Phoenix, Ariz.; Herb Shields, mechanical engineer and pilot, Equipment Development Center, Forest Service, U.S. Department of Agriculture, Arcadia, Calif.; James B. Davis, project leader, fire control methods, Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif.; and Floyd Waklee, equipment engineer and pilot, and Clinton B. Phillips, coordinator of forest fire research, both of the California Division of Forestry, Sacramento, Calif.

Why We Made the Inspection

Ever since 1956 when the air tanker became a member of the fire control team, firefighting agencies have been concerned with the possibility of corrosion damage from fire retardants to aircraft. This possibility has become particularly evident since salt solutions were introduced as fire retardants; such materials are good electrolytes and known to corrode some metals. Consequently laboratory studies were conducted both by chemical manufacturers and governmental agencies to evaluate corrosion and to develop corrosion inhibitors. One extensive test by the U.S. Forest Service's Arcadia Equipment Development Center dealt primarily with stress and fatigue corrosion (fig. 1). In general, these studies indicated that some fire retardants that had no corrosion inhibitors could cause corrosion (U.S. Forest Service, 1965).

Although laboratory tests by the manufacturer indicated that adequate corrosion inhibitors were in use, we still wanted to be sure about their effectiveness. During 1964, reports from air tanker operators tended to be contradictory: Most operators reported no indication of corrosion; a few were highly concerned about damage to their aircraft.

How We Made the Inspection

After the 1964 fire season, a team of inspectors from fire control agencies and chemical companies carefully examined 26 air tankers that had been used during the year (fig. 2). We also checked four non-air tanker aircraft that were intended as controls (table 1 and table 5 in Appendix).

The inspectors followed Arcadia Equipment Development Center's Guide for systematic inspection. The list includes: Unpainted aluminum surfaces; all magnesium parts; spot welds; fittings, braces, and compound parts inside the aircraft's tank compartment where chemicals or moisture may accumulate; hinges; areas where moisture in gels and chemical slurries does not evaporate readily; wheel wells; all brass parts such as control cable turnbuckles; lap joints; drain holes that may become clogged; areas where dissimilar metals are in contact; skin seams that trap and hold chemicals.

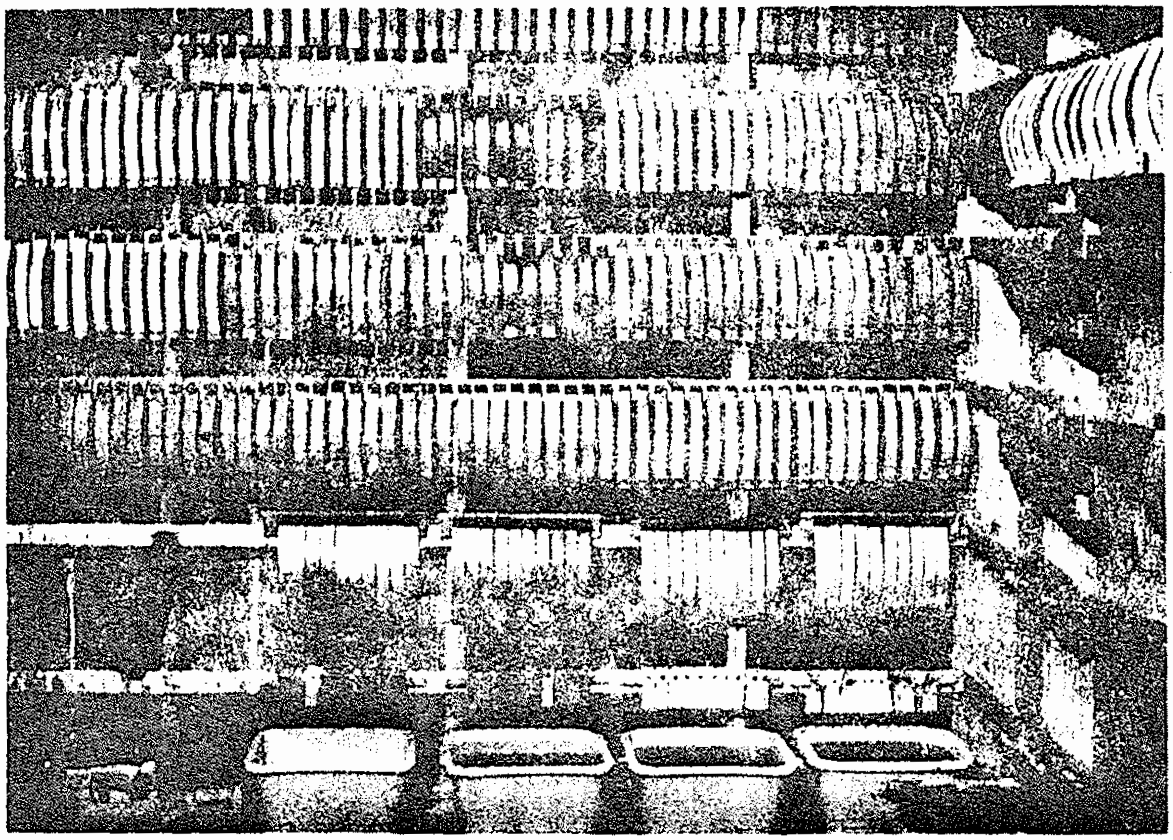

Figure 1.--Tests were conducted by the U.S. Forest Service's Arcadia Equipment Development Center to study weight loss stress and fatigue corrosion. Metal samples were bent to simulate stress corrosion and dipped for various lengths of time into fire retardant solutions. The number of pieces that cracked was recorded.

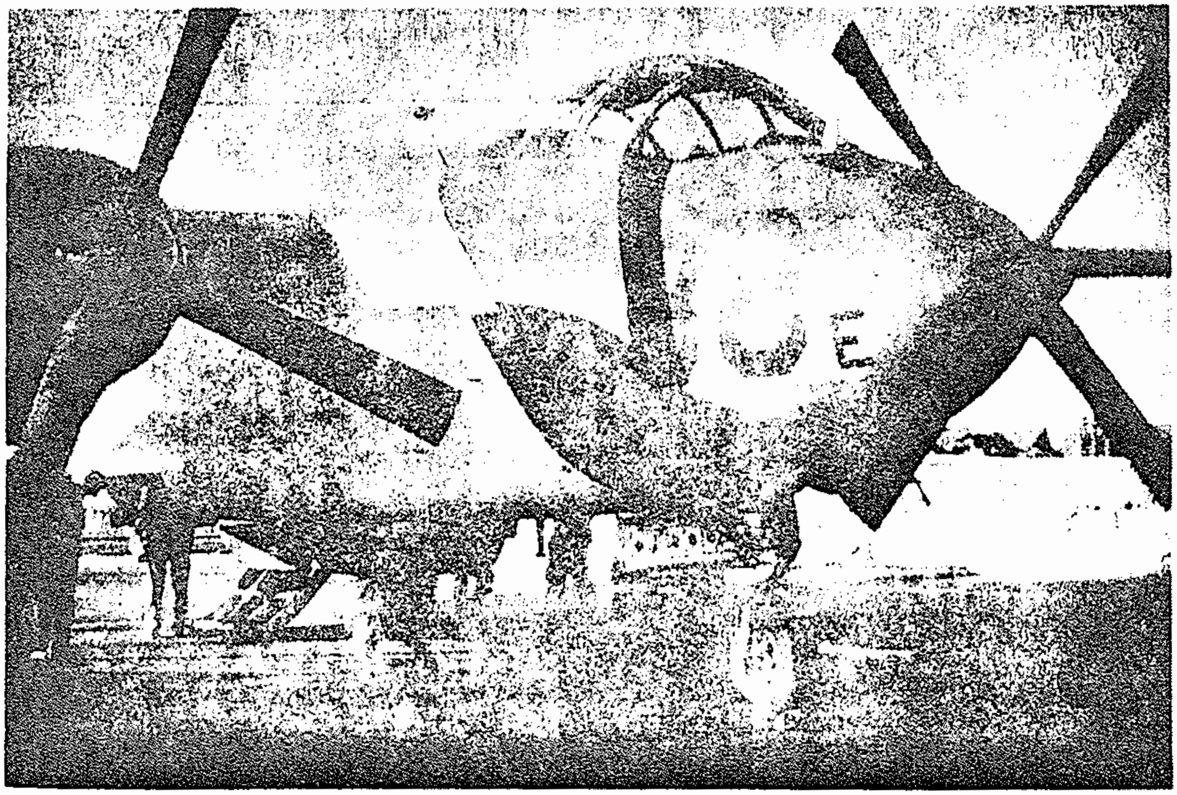

Figure 2.--The inspection team closely checked all visible parts of the

Table 1.--Number of aircraft having different degrees of corrosion on various parts of the aircraft.

Degree of Corrosion	Tank	Gate	Wings and Fuselage	Tail Assembly
26 AIR TANKERS				
None visible	7	6	21	17
Slightly pitted or rusted	12	12	5	8
Badly pitted or rusted	7	8	0	1
4 NON-AIR TANKERS[1]				
None visible	--	--	1	1
Slightly pitted or rusted	--	--	2	2
Badly pitted or rusted	--	--	1	0

[1] One aircraft had tail removed and missing.

Time and other limitations did not permit us to inspect the interiors of fuselages, wings, and other parts, except in one instance where a side panel was easily removed from the fuselage of an N3N. In many cases, the air tanker owner or operator made the inspection with us and helped point out problem areas.

What We Found

Almost 25 percent of the air tankers inspected showed no readily visible signs of corrosion, whereas 3 of the 4 non-air tanker aircraft inspected did show such signs.

Rust on mild steel parts was found on many parts of the aircraft, including tanks, gates, wheel rims, tail wheel assembly and well, framing and support structures, and bolts. In one case steel hinge pins inside a tank had rusted to the point that failure seemed imminent.

Tanks and gates fared far worse than the other parts of the aircraft--one or two tanks were in such bad shape that extensive repairs will be necessary. Corrosion damage in the tanks and on the tank gates may not endanger the airworthiness of the aircraft, but it does affect the aircraft operator's capital investment. Depending upon the size and design of the tank, replacements costs can be as much as $5,000.

Depth of pitting found in gates showed that, with one or two exceptions, the gates would not require replacement for 8 to 10 years if maintenance practices were continued as in the past. Those gates and tanks which showed no corrosion had in several cases received good protective coatings, such as properly applied fiber glass or epoxy resin.

Slight pitting was found on unpainted surfaces on the underside of the wing root of one TBM and two B-17 air tankers. Similar pitting was also found on a B-17 that had not been used as an air tanker.

The retardants most commonly used in the aircraft inspected were these three: Bentonite, Phos-chek (viscous diammonium phosphate), and Fire-trol (thickened ammonium sulphate). In addition, large quantities of algin gel were used (table 2).

Evidence was strong that the worst corrosion noted in tanks and gates was caused by algin gel. By far the worst example of corrosion was on an air tanker, E-68, that had carried algin gel almost exclusively in 1964. In two or three other cases of extensive tank and gate corrosion, the aircraft had carried several loads of algin gel during the 1964 fire season. These findings tended to confirm those of the corrosion tests conducted in 1963 by the Forest Service's Equipment Development Center (U.S. Forest Service, 1965).

In almost every case when we found corrosion we could relate damage to four important variables: (a) the kind of metal used in the construction of the air tanker and the tanks; (b) use of protective coatings; (c) quality of aircraft maintenance; and (d) type of retardants dropped.

Table 2.--Fire retardants used by fire control agencies in California during 1964.

Retardant	Calif. Div. of Forestry	U.S. Forest Service	Los Angeles Co. Fire Department
		Gallons of retardant (thousands)	
Bentonite	1,415.3	(1/)	--
Algin Gel	106.8	(1/)	--
Gelgard	78.4	(1/)	--
Water	18.0	(1/)	--
Fire-trol	871.0	(1/)	--
Phos-chek	781.0	(1/)	296.4
Shell-DAP	44.0	(1/)	--
Borate	37.9	(1/)	47.8
Total	3,352.4	3,699.7	344.2

1/ Breakdown of data on retardants used not available.

Recommendations

Based upon the findings of the inspection trip, we recommend the following procedures:

1. For the construction of tanks or other modifications to air tankers, choose metals or materials that resist corrosion or deterioration by chemical salt solutions. Consult with metallurgists.

2. For the construction of tanks and other related fittings, avoid the use of unclad aluminum alloys that contain high percentages of copper zinc or magnesium. These alloys generally would include the 2,000, most of the 5,000, the 7,000 series, and two or three other individual numbers of aluminum alloy (see table 5 in appendix).

3. Avoid the use of mild steel and magnesium whenever another more corrosion resistant metal will do the same job. This recommendation applies especially to hinges, braces, bolts, nuts, washers, and other tank interior parts.

4. Check to see that all parts of a tank or of other modifications in the construction of an air tanker are made from the same metals or metals that do not promote corrosion when in contact. Contacts between some dissimilar metals, even some dissimilar alloys of the same metal, can greatly accelerate corrosion.

5. Protect all exterior surfaces of aircraft that come in contact with the corrodent. No corrosion damage was found on exterior surfaces which were well-painted and maintained in that condition.

6. Coat tank and gate interiors with epoxy resins which use no amine catalyst, fiber glass laminated by epoxy resins, or vinyl resins.

6. (cont'd) Follow the manufacturer's recommendations closely and, if possible, have the work done by a shop recommended by the manufacturer. More study is needed on the subject of protective coatings--it may be that other types of coatings can be recommended in the future.

7. Where any coupling of surfaces takes place and fire retardant is present at the junction, protect the metal by applying vinyl or polyester tape to both surfaces. The most important such coupling on an air tanker is where the tank and gate surfaces meet.

8. Do not use fire retardants that have not been approved by the contracting forest fire control agencies. This approval is given only after the retardants have satisfactorily passed rigid tests performed by the agencies.

9. Follow good aircraft maintenance practices to minimize corrosion damage from any source.

10. Wash the fire retardant residue from all exterior portions of the air tanker as soon as possible upon returning to base after a fire control action. Accumulated retardant will retain moisture or will attract it from the air. This moisture combined with retardant salts causes corrosion.

11. Inspect regularly the paint on exterior portions of the aircraft. Where bare metal is exposed, clean the surface and apply new primer and finish coats of paint.

12. Flush regularly with water and inspect the interior of the tank. Where bare metal is exposed, apply new protective coatings.

13. Inform the air tanker base manager of observed evidence of corrosion. If all other precautions have been taken (use of recommended metals and protective coatings, proper maintenance, etc.), the retardant may be at fault and corrective action must be taken at once.

14. If chemical pumping capacities are adequate for fast loading, consider keeping aircraft on standby empty.

The following appendix provides additional details on corrosion, on the details of the investigation made by the six-man task force in California, and on the reasons for the recommendations outlined above.

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Appendix:

Corrosion - What is it?

Webster defines corrosion as "to eat away by degrees as if by gnawing." Possibly a more precise definition is "the destruction of metal by chemical or electrochemical action; a familiar example is the rusting of iron" (Uhlig, 1948). Corrosion occurs because most metals tend to return to their natural state (iron in the presence of moist air will revert to its natural state of iron oxide). Metals are also corroded by the direct reaction of the metal to a chemical.

Almost any chemical action can be regarded as electrochemical; it is accompanied by the transfer or displacement of electrons. Four elements must be present before electrochemical corrosion can occur (fig. 3):

1. An electron emitter (Cathode).
2. An electron receiver (Anode).
3. A continuous liquid path (electrolyte--in our case a fire retardant salt).
4. A conductor to carry the flow of electrons from the Anode to the Cathode. It is usually in a form that provides for metal-to-metal contact (rivets, bolts, welds, etc.).

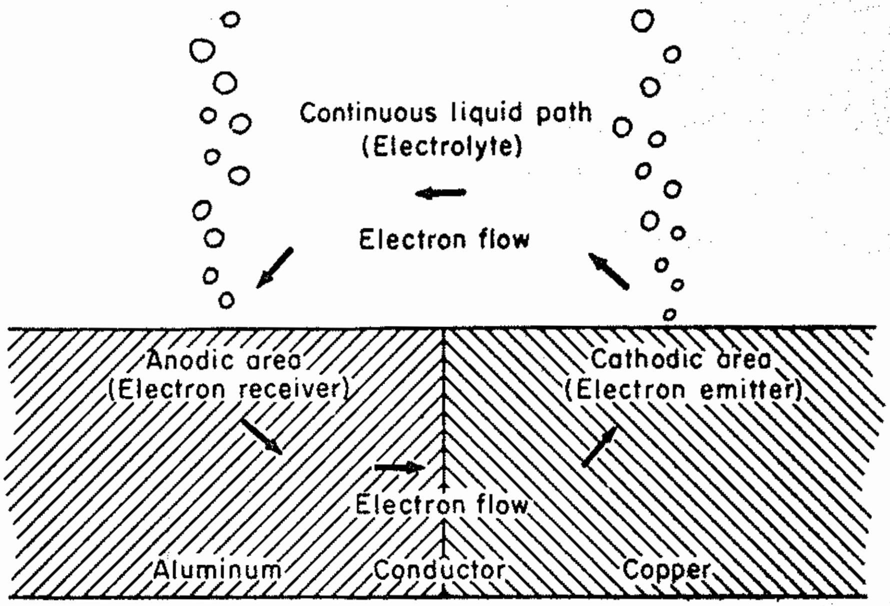
The presence of a second metal is not needed for electrochemical action. Local chemical or physical differences in or on the metal, such as the presence of copper in an aluminum alloy, will develop numerous Anodic and Cathodic areas interspersed over the surface.

TYPES OF CORROSION

For descriptive purposes, corrosion can be broken down into eight different types (Department of the Air Force, 1964).

1. UNIFORM ETCH CORROSION On a polished surface is first noticed as a general dulling of the surface.

Figure 3.--Conditions for electrochemical corrosion (from Department of the Air Force Manual 52-11, 1964).



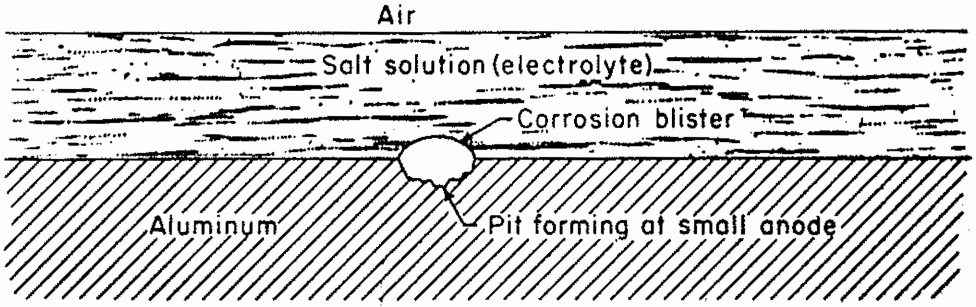


Figure 4.--Pit corrosion forming on aluminum surface.

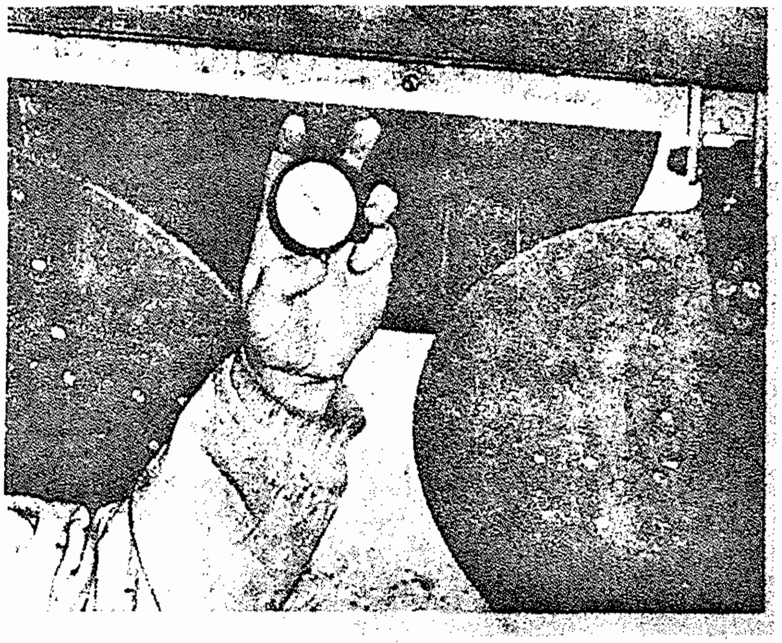


Figure 5.--Depth of corrosion action can be measured with a pit depth gage.

Figure 6.--Grain boundaries in stainless steel along fracture edge adjacent to an overheated silver soldered joint (California State Division of Highways Engineering Report). Magnified 1000 times.

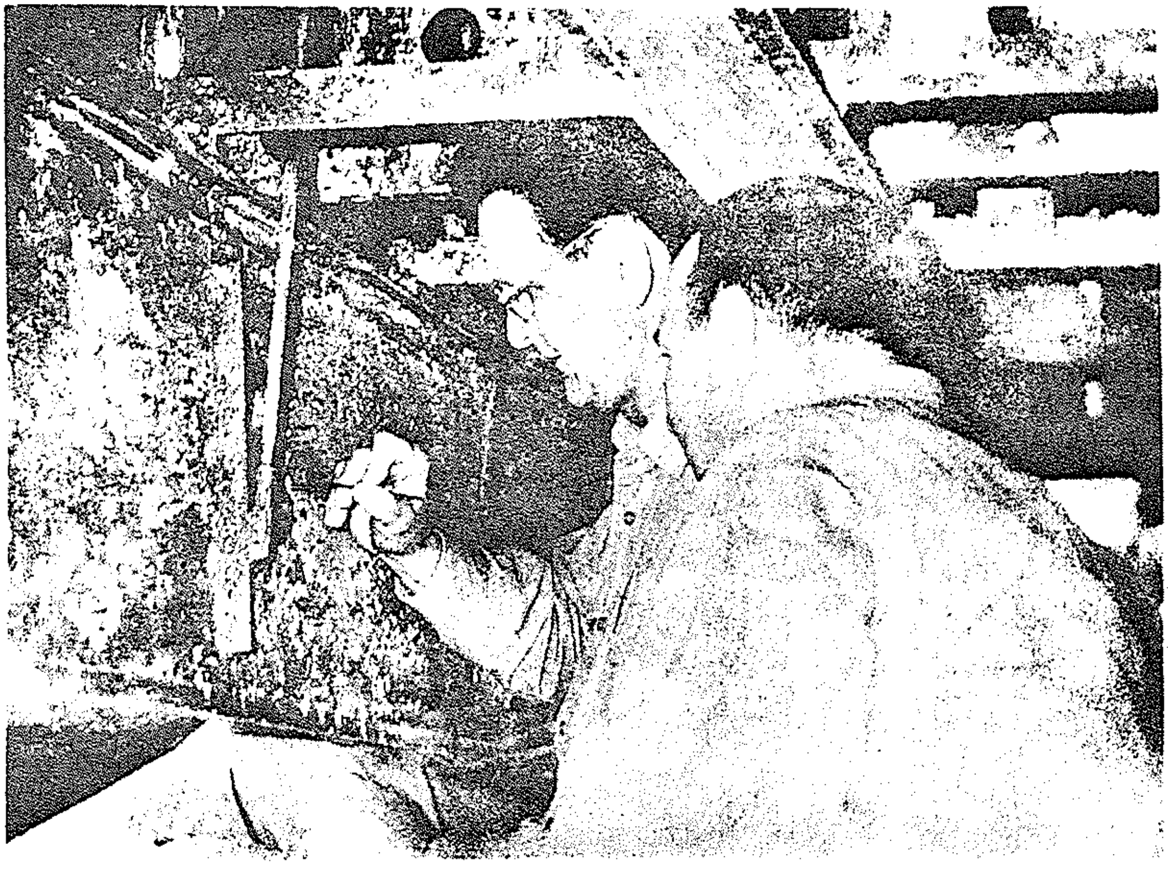


Figure 7.--Exfoliation of aluminum tank gate of an air tanker is pointed out by an inspector. White area being examined is caused by corrosion occurring between grains within the aluminum alloy.

1. (cont'd) If this form of corrosion is allowed to continue, the surface becomes rough and possibly frosted in appearance.

2. PITTING CORROSION The most common effect of corrosion on aluminum and magnesium alloys. It is first noticeable as a white or gray powdery deposit similar to dust which blotches the surface. When the deposit is cleared away, pits or holes can be seen in the surface (fig. 4, 5).

3. INTEGRANULAR CORROSION Results from an attack on the grain boundaries of a material. A highly magnified cross section of a commercial alloy shows the granular structure of the metal (fig. 6). When in contact with specific types of electrolytes, the adjacent grains of the metal and the elements in the grain boundary can act as Anodes and Cathodes.

4. EXFOLIATION CORROSION A form of integranular corrosion in which the surface grains or layers of a metal are "lifted"-up by the force of expanding corrosion products occurring at the grain boundaries below the surface. It is most often seen on extruded sections of metal where the metal grains have been greatly elongated in one direction (fig. 7). It can also result when the heat treatment is too short or is at too low a temperature. Exfoliation corrosion can also be the result of alloy segregation. After rolling or extrusion, the corrosion will follow these layers of segregated alloys.

5. GALVANIC CORROSION Occurs when dissimilar metals are in contact and an external circuit is provided by a buildup of corrosion at the joint between the metals. For example, when aluminum pieces are attached by steel bolts or screws, galvanic corrosion can occur between the aluminum and the steel. The most likely areas of corrosion would be on the aluminum and would be around or beneath the periphery of the head of the steel bolt.

6. CONCENTRATION CELL CORROSION Occurs when two or more metal surfaces are in contact with different concentrations of the same solution. Such a situation exists when partially evaporated retardant spills are trapped against the outside of the aircraft tank. It can also occur when any flushing with water is not complete.

7. STRESS CORROSION CRACKING Caused by the simultaneous effects of tensile stress and corrosion. Stress may be internal or applied. Internal stresses are produced by non uniform deformation during cold working; by unequal cooling, improper annealing or heat treating; and by internal structural rearrangement involving volume changes. An example of stress is a bolt or rivet under tension. Studies conducted by the U.S. Forest Service, Equipment Development Center (1964) showed that this form of corrosion can occur in metals stressed to near the yield point and exposed to some fire retardant solution. Stress corrosion is difficult to recognize before it has overcome the design safety factor of the metal involved. The presence of tensile stress and corrosion, however, does not necessarily result in stress corrosion. In addition to stress, it is necessary that the metal can metallurgically support this form of corrosion and that the corrodent will cause stress corrosion to occur.

8. FATIGUE CORROSION A special form of stress corrosion caused by the combined effect of cyclic stress and corrosion. No unprotected metal is immune to some reduction of its resistance to cyclic stressing if the metal is in a corrosive environment. Fracture of a metal part due to fatigue corrosion generally occurs at a stress far below the normal fatigue limits even though the amount of visible corrosion may be unbelievably small. For this reason, protection of all structurally important parts subject to alternating stress is particularly important, even in environments that are only considered to be mildly corrosive.

METALS USED IN BUILDING AIRCRAFT AND TANKS

Metals used in aircraft and tank construction are an important factor that affects corrosion. In most cases we found that the tank and gates were made from military surplus materials. Often the builder had no information on the physical and mechanical properties of the material he was using. This was particularly true in the case of aluminum. Unfortunately the name "aluminum" is indiscriminately applied to the unalloyed metal and to all its alloys. These materials behave very differently among themselves (tables 3, 6).

The resistance of pure aluminum to corrosion is quite high (Evans, 1960). But pure aluminum is relatively weak; its use is limited. Consequently it is combined with one or more elements.

Those alloys containing copper, although stronger than the others, are the least resistant to corrosion. If incorrectly heat treated, they become liable to integranular corrosion or in some cases to layer corrosion with swelling and exfoliation. Under tensile stress, stress corrosion cracking may develop.

Table 3.--Composition and mechanical properties of some aluminum alloys found on most air tankers.

Alloy number	Composition	Tensile strength(psi)	Elongation (Pct. in 2 in.)
1100	"Commercially Pure" Aluminum	13,000	35
3003	Aluminum + 1.2 Pct. Manganese	29,000	4
2024	Aluminum + 4.5 Pct. Copper + 0.6 Pct. Manganese + 1.5 Pct. Magnesium	68,000	19
5052	Aluminum + 2.5 Pct. Magnesium + 0.25 Pct. Chrome	29,000	25
6061	Aluminum + 0.25 Pct. Copper + 0.6 Pct. Silica + 1.0 Pct. Magnesium + 0.25 Pct. Chrome	35,000	22
2024 Alclad	Duplex Product with 2024 Core and 1230 (Similar to 100) Cladding	64,000	18

Cladding--the application of nearly pure aluminum to one or both sides of an aluminum alloy sheet--is the principal corrosion preventative in air frame structures. Generally the core is a high strength alloy that makes up about 90 percent of the sheet thickness.

The pure aluminum coatings are metallurgically bonded to the core over the entire area of contact. In most widely-used alclad materials, the coating alloys are selected so that they will be anodic to the core alloys in most natural environments. Thus the coating will electrolytically protect the core where it is exposed at cut edges, rivet holes, or scratches. Under normal conditions, alclad aluminum is highly resistant to corrosion; however, accumulated soil and salts will attract moisture and cause pitting of the alclad surface. Since cladding produces no striking alteration in appearance, its very existence may not be known--giving rise to the belief that "aluminum" can always be left unpainted.

Since corrosion is accelerated when dissimilar metals are in contact, care should be taken to place similar metals together. Metals grouped together in table 4 do not tend to produce galvanic corrosion and are relatively safe to use in contact with each other. The coupling from different groups and distant from each other in table 4 will usually result in galvanic or accelerated corrosion of the metal higher on the list. The farther apart the metals are in the table, the greater will be the galvanic tendency. We frequently found various aluminum alloys (Group I or II) bolted to steel (Group III) in tanks that showed considerable corrosion to both aluminum and steel.

The inspection team found frequent pitting and etch corrosion on unprotected aluminum surfaces on all parts of the aircraft. Such corrosion occurred whether the aircraft had been used as an air tanker or not, pointing out that cladding of aluminum is not a positive deterrent to corrosion. Some of the worst etching was found on the fuselage of a junked C-45 that had never carried fire retardants.

In only one case did we find corrosion on well-painted surfaces, outside the tanks and gates. A few pits 1 to 3 mils deep were found on one TBM (air tanker E-95) that had carried mostly algin gel in 1963.

Table 4.--Grouping of metal and alloys considered similar as to galvanic corrosion.[1]

Group	Metal or alloy
I	Magnesium and its alloys; aluminum alloys 5056, 5356, 6061 and 6063
II	Cadmium, zinc, and most aluminum alloys
III	Iron, lead, and tin, and their alloys (except stainless steel)
IV	Copper, chromium, nickel, silver, gold, platinum, titanium, cobalt, and rhodium and their alloys; stainless steel and graphite

[1] Metals classified in the same group are considered similar to one another; those in different groups are considered dissimilar to one another.

When practical, rivets, bolts, and other fasteners should be made of the same material as the main structure. Stainless steel has been successfully used as a fastener on aluminum in mildly corrosive environments. When not practical fasteners should be selected from materials lower in table 4 in order to distribute the anodic attack over the larger of the two coupled metals. This step is particularly vital if fasteners are subjected to high stress and where the safety factor is low. Caution should be exercised, however, when fasteners are made from a metal that is higher in table 4.

Since corrosion is a potential problem with any of the fire retardants now in use, its prevention or control should be one of the most important considerations in new tank and door construction. Most aluminum companies will be able to assist a builder in constructing a tank that is adequate from both a physical as well as a corrosion standpoint.

PROTECTIVE COATINGS

The inspection team found that the use of protective coatings was critical in helping to prevent or reduce corrosion damage. An organic film or paint properly applied to metal surfaces will prevent the electrolyte from connecting the Cathode to the Anode. In the case of bi-metallic contacts, either both metals should be coated, or if circumstances require, the metal which is in the lower group (i.e. IV, see table 4) should be coated.

We found corrosion inside several tanks and gates where rust preventative paint and primer had been used. In a few cases this corrosion could have been caused by algin gel that was carried in tanks treated with zinc chromate primer. This combination forms zinc alginate salt, which accelerates pit corrosion.

The lack of a protective coating inside the tanks and gates seems much more likely to result in corrosion. This possibility was seen in the steel parts. The inspection team found several tanks treated with epoxy resins or fiber glass which showed virtually no corrosion.

Several of the types of protective coatings that can be used to protect aircraft surfaces are: (a) organic paints; (b) epoxy, polyester, and vinyl resins; (c) vinyl or polyester tape; (d) fiber glass; and (e) mastics and neoprene.

In each case the key to successful use of protective coatings is in (a) proper preparation of the surface to be protected, and (b) proper application of and in some cases, the curing of the coating material. In preparing the surface, all signs of prior protective coatings and of corrosion must be removed by grinding or sand blasting. In applying the protective coating, follow the manufacturer's specifications. Many manufacturers or dealers are willing to recommend commercial applicators.

ORGANIC PAINTS Organic paint seems to be inferior to other materials for coating tank and gate interiors. The inspection team found that an organic paint simply did not hold up well. And, in one or two instances noted above, it actually reacted chemically with the fire retardant to accelerate corrosion.

While paint may not be the best answer for tank interiors, it works well on aircraft exteriors. Corrosion damage was found on only one small area on air tanker E-95 where paint had been applied. Otherwise, paint seemed to provide complete protection for aircraft exterior surfaces.

EPOXY, POLYESTER, AND VINYL ESTERS Epoxy resins are one of the most versatile of the maintenance coatings designed to resist chemicals, solvents, water, and abrasion. An outstanding characteristic of epoxy resins is their excellent performance when submerged for long periods in salt water or brine solutions (Ahrberg, 1964).

Considerable care should be taken to see that the proper epoxy resin is used. Resins used in tank construction should not contain amine. Amine catalysts may be responsible for weakening epoxy resins that are continuously in water (Bell, 1957).

Allgood, et.al., (1964) reported wide variation in the effectiveness of epoxy resin paints exposed to the atmosphere of a manufacturing plant producing phosphate and nitrogen fertilizers. In one test area where 24 tests of catalyzed epoxy paints had been conducted, the variations in durability ranged from 7 to 82 percent (fig. 8). These variations are attributed to differences in the raw materials used and to the methods used in paint manufacture.

Polyester resins are used in the construction of most fiber glass boats. They have many of the same characteristics and uses as epoxy resins. Although polyester coatings cost about half as much as epoxy coatings, they do not adhere as strongly to metal.

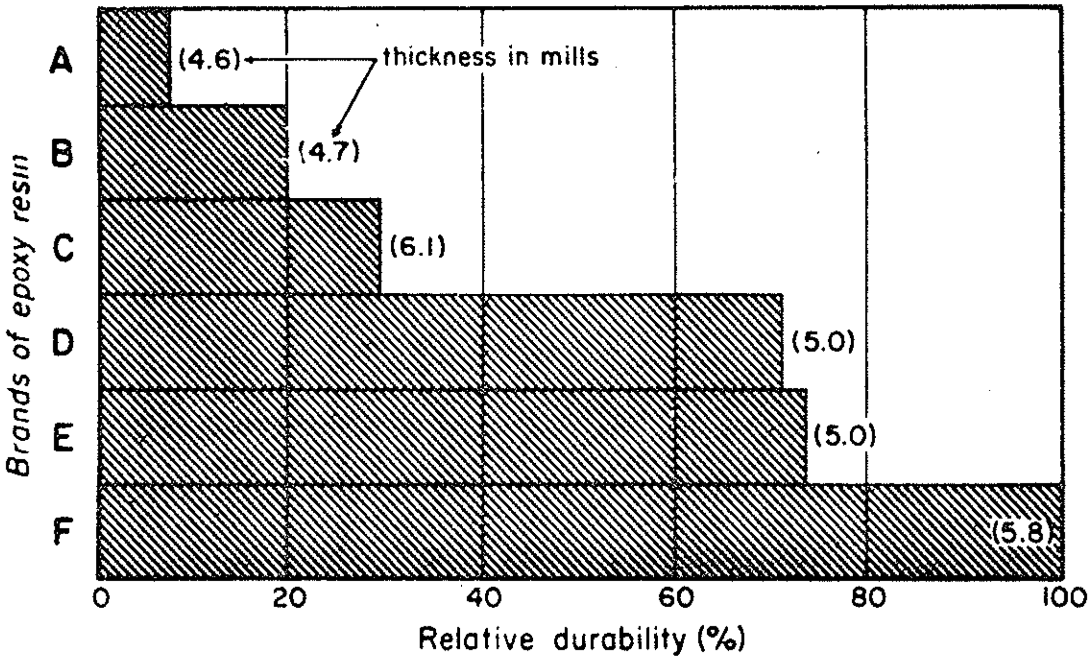


Figure 8.--Typical variations in relative durability of epoxy resin coatings that have about the same thickness.

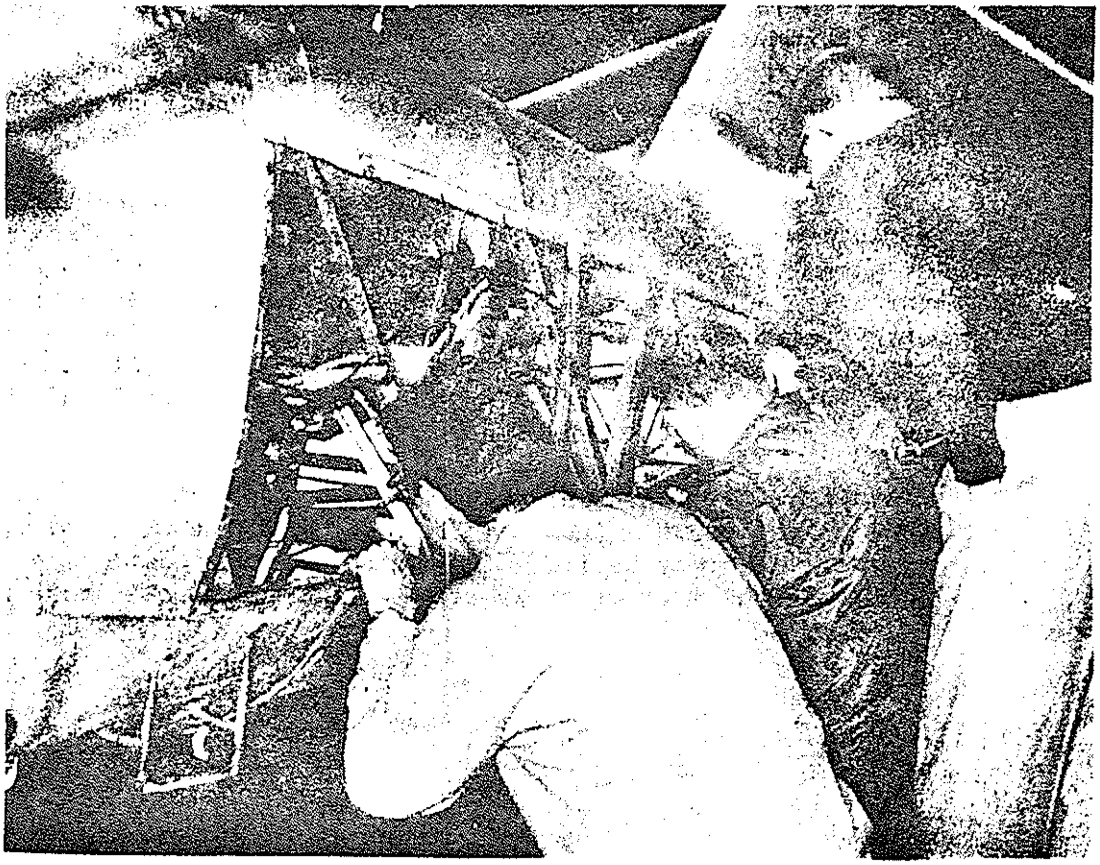


Figure 9.--Some air tankers showed virtually no corrosion--largely because of high quality maintenance.

If polyester or epoxy coatings are used, the air tanker operator should insist on an applicator that knows his business. The quality of the end product depends on several factors. For example, too much catalyst can cause the resin to become brittle and crack, and form anodic corrosion (Morgan, 1957). We found one case in which a poor job resulted because the weather was too cold at the time of application. While tank interior coatings may help overcome an unfortunate choice in tank construction material, the right coating material should be selected. A number of light coats helps to minimize pin holes.

Vinyl resins are different from epoxy resins in that the end product is quite plastic rather than rigid. Such plasticity has its advantages if metal surfaces must stand stress and strain. On the other hand, the harder epoxy resins have more resistance to abrasion and impact forces. Vinyl must be applied with the same exacting care as epoxy, and requires an applicator who is thoroughly experienced and highly recommended by the manufacturer of the product. Although epoxy, polyester and vinyl resins are immune from electrochemical corrosion, they are still subject to chemical attack. Most polyester resins, for example, are not recommended for use when solution pH is above 10 (Oleesky, et.al., 1964).

VINYL AND POLYESTER TAPE Continuity of the liquid path may also be broken by the use of vinyl or polyester tapes. If conditions favorable to galvanic corrosion cannot be avoided, always try to protect both portions of a metal joint. A break in the protective coating on the anodic surface will cause severe pitting if the cathodic surface is not protected because of the concentration of current upon the relatively small area exposed. The attack is made even more intense because the Anode is small compared to the Cathode. Therefore, if there is a requirement that only one surface be coated, always coat the cathodic area. This is particularly true when the inside of the tank is coated with epoxy or polyester resin. A typical place where tape might be used is where gates are sealed against the tank. Tape would be applied to both the tank and the gate sealing surfaces.

FIBER GLASS Steel or aluminum tanks can be covered with fiber glass to protect them from rust or corrosion. The fiber glass should be similar to the types required for marine use and contain a water repellant chrome finish.

It should be cloth, rather than rovings or mat, and of the weave most suitable for the particular tank design.

Two layers of medium weight cloth have been found to give better protection on metal boat hulls than a single layer of heavy cloth. They should also protect aircraft tanks. Epoxy resins must be used to laminate the glass fabric to the tank.

MASTICS AND NEOPRENE Mastics and neoprene have long been used to line water tanks and serve as protective coatings in other industrial uses. Experience by forest fire control agencies has shown that these materials are not nearly as satisfactory as epoxy, polyester, vinyl resins, or fiber glass for protecting water tank interiors from corrosion over long periods of time. Manufacturers of mastics and neoprene do not recommend them for chemical storage. Other coatings, while more expensive to apply, would probably be more economical and more satisfactory over the long haul.

Poorly applied coatings of all types that develop cracks or pin holes usually aggravate the situation. Normal aircraft flexing in flight requires careful continued checking at points of flexure, such as corners and sharp bends. If separation of coatings occur along with pin holes, liquids can "get behind" the lining and remain unseen until the damage has developed. Removal and replacement then can be difficult.

MAINTENANCE

During the course of the inspection trip, we found a great deal of variation in maintenance and good housekeeping practices (fig. 9). While some air tankers were spotless, others contained a thick deposit of dried retardants layer on layer much like that in geological formations. These layers served to show the life history of the air tanker for the past fire season or two.

Moisture tends to collect on dirt particles, increasing electrical conductivity and accelerating corrosion. The maintenance of clean surfaces on passive metals, such as aluminum or on aluminum alloys, can be of greater importance than on plain carbon steel or copper based alloys.

If small corrosion areas begin to develop, the combination of these small active Anodes to large passive Cathodes can cause severe pitting. Alloys that owe their corrosion resistance to passivity are particularly susceptible to accelerated corrosion within crevices.

In comparing aluminum to steel in an ordinary situation, a distinction must be made between the exposed portions and recesses. Unpainted steel will probably show red rust in a few days on the exposed surface; aluminum may remain almost unchanged in appearance and will probably suffer very little on the exposed surface over long periods. But at the crevices formed where aluminum comes close to another material--or even to a second aluminum surface--it may be severely attacked--and at those places least likely to be observed. If the aluminum alloy includes copper, the attack may take the form of layer corrosion. And, severe exfoliation may slowly develop undetected.

Although steel produces a conspicuous red corrosion product (rust)--generally on those parts most visible to view--aluminum may produce an inconspicuous white product at the point least accessible to inspection.

For these reasons, cleanliness must be maintained, coupled with an adequate systematic inspection. The Forest Service Equipment Development Center recommends that each air tanker be checked after a day's operation by authorized inspectors. It also recommends that periodic air tanker inspection checklists be expanded to include critical parts inspections of in-flight and other vital structural systems.

FIRE RETARDANTS

In general the flame-retarding chemicals with their built-in corrosion inhibitors appear to be no more of a problem than gelled liquids such as Bentonite.

Corrosion inhibitors are being prepackaged with the commercial retardants Fire-trol, Phos-chek, and Shell-DAP that use ammonium phosphate and ammonium sulphate. These two chemicals are strong electrolytes that can cause severe corrosion to several metals common to aircraft, including aluminum, magnesium, and copper.

Corrosion reduction in commercial retardants is accomplished chemically either by an insoluble film that "stifles" further corrosion, or by a protective oxide coating that makes the material passive. Examples of anodic inhibitors include additions of chromates, phosphates, and silicates to decrease corrosion rate. These substances probably help to form or maintain a protective film on the metal surface.

Bentonite is considered to be non-corrosive. It was the only retardant used in three air tankers and each showed signs of corrosion--primarily rusting of steel parts, probably from the moisture in Bentonite.

Algin gel without corrosion inhibitors appears to cause serious corrosion damage to aluminum alloys (fig. 10). Exfoliation-type corrosion and pits as much as 70 mils deep developed during one year in air tanker E-68, that carried mainly algin gel. The Arcadia retardant tests showed stress-corrosion cracking in aluminum alloy 2024-T4 after continued exposure of about 300 days to algin gel. The material appeared to be more corrosive to this aluminum alloy than any other retardant tested. Algin gel is now being phased out of the air tanker program by all forest fire control agencies in California.

The successful use of inhibitors requires considerable knowledge of their action on different metals and a thorough understanding of the corrosion process in the system under consideration. A substance may successfully decrease the rate of attack on a metal or practically stop corrosion entirely in one environment, but may in another environment stimulate it.

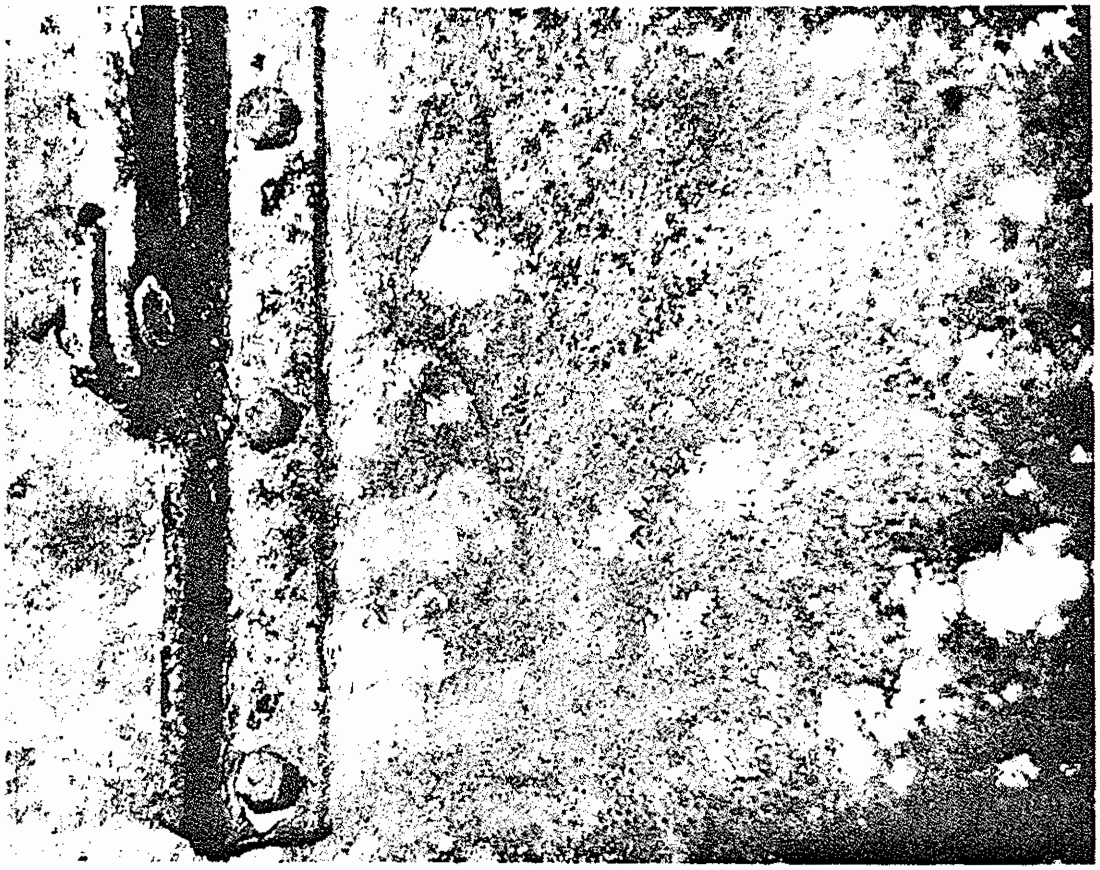


Figure 10.--Deep pits and exfoliation appeared on the gates of this air tanker after it had carried algin gel for one fire season.

Table 5.--Corrosion found on aircraft in California, 1964

AIR TANKERS

Tanker number	Aircraft type	Retardant[1/]		No. Drops 1964	Corrosion				Remarks
		1963	1964		Tank	Gates	Wings and fuselage	Tail	
E-5	N3N-3	--	B-90pct. GG-5pct. PC-5pct.	--	None detected	None detected	None detected	None detected	Fuselage, wings and tail assembles painted. No corrosion inside of fuselage behind cockpit. Metal tank coated with fiber glass.
E-17	B-17G	--	FT AG B	--	Steel fittings badly rusted. Few pits outside.	Steel fittings badly rusted.	Pit corrosion on wing flaps and horizontal stabilizer and elevator.	Tail wheel support yoke badly rusted.	Bluing on some brass parts.
E-18	B-17G	B AG	B-25pct. AG-20pct. FT-50pct. GG-5pct.	350	Slight rusting on bolts, etc.	Slight rusting on bolts, etc.	Pit corrosion on wing flaps inboard of 1st engine both sides.	Bluing on brass parts in tail well.	Pits on flaps 2-3 mils deep. Rust on structure member ahead of tank and on wheel rims.

See footnote at end of table.

Table 5.--Corrosion found on aircraft in California, 1964, continued

AIR TANKERS

Tanker number	Aircraft type	Retardant[1/]		No. Drops 1964	Corrosion				Remarks
		1963	1964		Tank	Gates	Wings and fuselage	Tail	
E-29	TBM-3	B-10pct. FT-90pct.	B-24pct. FT-73pct. GG-1pct. PC-2pct.	300	Slight pit corrosion inside.	Rust on steel bolts.	None detected	Slight rusting in well.	Tail light cable in tail wheel well shows some corrosion products. Bluing on brass level valves for drop-tank.
E-30	AF-2S	B AG P	B-20pct. AG-25pct. FT-50pct. PC-5pct.	150	Slight rusting	Slight rusting	Etching on exterior.	Slight rusting in tail well.	Bluing on brass camlocks.
E-34	B-17F	B	PC-75pct. FT-20pct. B-5pct.	250	Some rust on steel parts.	Some rust on steel parts.	Some rust on steel parts.	None detected	No pit corrosion of type found on wings of Nos. E- and E-18. Many areas well-painted.
E-35	F-15A	--	PC-75pct. FT-20pct. B-5pct.	175	None detected	None detected	None detected	None detected	Very clean plane.

See footnote at end of table.

Table 5.--Corrosion found on aircraft in California, 1964, continued

AIR TANKERS

Tanker number	Aircraft type	Retardant[1/]		No. Drops 1964	Corrosion				Remarks
		1963	1964		Tank	Gates	Wings and fuselage	Tail	
E-41	F7F-3	--	B AG FT PC GG	--	Slight rust on steel parts.	Slight rust on steel parts.	None detected	None detected	Very clean plane.
E-42	F7F-3	AG B	B PC FT BO	--	Slight rust on steel parts.	Slight rust on steel parts.	None detected	None detected	Very clean plane. Stainless steel bolts inside tank very clean after several years.
E-46	TBM-3	B-100pct.	B-24pct. FT-73pct. GG-1pct. PC-2pct.	200	Fittings and tank badly rusted.	Badly rusted.	None detected	None detected	Steel tank and gates. Bluing on brass camlock fittings.
E-57	TBM-3	--	B AG FT PC GG	--	Rusty	Rusty	None detected	Rust in tail wheel well.	Steel tank. Fuselage well painted.

See footnote at end of table.

Table 5.--Corrosion found on aircraft in California, 1964, continued

AIR TANKERS

Tanker number	Aircraft type	Retardant[1]		No. Drops	Corrosion				Remarks
		1963	1964	1964	Tank	Gates	Wings and fuselage	Tail	
E-61	B-17G	B PC	B	10-15	None detected	Some pit corrosion. Some rust.	None detected	None detected	Tank gates fabricated of 75 T aluminum alloy. Pits up to 5 mils deep. Some bluing on brass camlock fittings.
E-68	TBM-3	Not used	AG-95pct. FT-4pct. PC-1pct.	275	Seams on structural parts show pit corrosion. Few on vertical sides.	Inside badly pitted. Much exfoliation. Pits up to 70 mils deep.	None detected	Salt deposits in tail wheel well. No corrosion.	Gates show worst pitting of any aircraft inspected. Sample of alloy and corrosion product taken for analysis. Gates (aluminum 7075) and tank sandblasted and painted prior to 1964 use.

See footnote at end of table.

Table 5.--Corrosion found on aircraft in California, 1964, continued

AIR TANKERS									
Tanker number	Aircraft type	Retardant[1/]		No. Drops 1964	Corrosion				Remarks
		1963	1964		Tank	Gates	Wings and fuselage	Tail	
E-71	TBM-3	--	B-45pct. PC-50pct. AG-1pct. FT-4pct.	--	Slight rust	Some exfoliation and pit corrosion before sandblasting and painting in Oct. 1964.	None detected	None detected	Plane exterior painted.
E-72	TBM-3	--	B-40pct. FT-50pct. BO-8pct. AG-2pct.	75	Steel fittings badly rusted. Pit corrosion on aluminum.	Inside shows considerable pitting.	None detected	Slight rust in tail wheel well.	Pits on gates 20-30 mils deep. Fuselage painted.
E-73	TBM-3	--	B PC FT	--	Some pit corrosion. Steel fittings rusty.	Some pit corrosion inside. Some rust.	None detected	None detected	Fuselage painted. Inside of tank and gates painted well.

See footnote at end of table.

Table 5.--Corrosion found on aircraft in California, 1964, continued

AIR TANKERS									
Tanker number	Aircraft type	Retardant[1]		No. Drops 1964	Corrosion				Remarks
		1963	1964		Tank	Gates	Wings and fuselage	Tail	
E-75	TBM-3	--	PC-95pct. FT-4pct. B-1pct.	200	None detected	Slight pit corrosion. Slight rust.	None detected	None detected	Plane exterior painted.
E-77	AJ-1	BO-99pct. AG-1pct.	PC-90pct. FT-4pct. B-1pct. BO-5pct.	--	None detected	None detected	None detected	None detected	Very clean plane. Inside of tank has epoxy coating.
E-78	B-17G	--	B-75pct. PC-15pct. FT-10pct.	--	None detected	Steel fittings rusty	None detected	None detected	No pit corrosion of type found on Nos. 17 and 18. Tank 24S clad aluminum. Some bluing on brass camlock fittings.
E-88	AJ-1	BO-99pct. AG-1pct.	PC-90pct. FT-4pct. B-1pct. BO-5pct.	--	None detected	None detected	None detected	None detected	Flapper valve of 75T aluminum alloy in drop-tank shows pit corrosion. Very clean plane. Inside of tank has epoxy coating.

See footnote at end of table.

Table 5.--Corrosion found on aircraft in California, 1964, continued

AIR TANKERS

Tanker number	Aircraft type	Retardant 1/		No. Drops 1964	Corrosion				Remarks
		1963	1964		Tank	Gates	Wings and fuselage	Tail	
E-92	TBM-3	Not used. Tank sand-blasted and painted.	PC-75pct. FT-25pct. B-1pct.	350	Slight rust on steel parts.	Small amount of pitting along steel gate support possibly galvanic.	None detected	None detected	Bluing on brass overflow valves and camlock. Plane exterior painted. Tank painted inside and out.
E-93	PBY-6A	--	B FT PC	--	Some galvanic and exfoliation.	Some galvanic and exfoliation.	None detected	None detected	--
E-95	TBM-3	AG	FT	--	Steel fittings badly rusted.	None detected	Pit corrosion on wing flaps, 1-3 mils deep.	Few pits on horizontal elevator and stabilizer.	Gates ground and painted with poly form after algin gel use in 1963.

See footnote at end of table.

Table 5.--Corrosion found on aircraft in California, 1964, continued

AIR TANKERS

Tanker number	Aircraft type	Retardant[1]		No. Drops 1964	Corrosion				Remarks
		1963	1964		Tank	Gates	Wings and fuselage	Tail	
E-96	TBM-3	AG	BO B PC FT	--	Slight rust.	None detected	None detected	Slight rust in tail wheel well.	Plane at Paso Robles during fire season.
E-97	TBM-3	--	BO B PC FT	--	Rusty	Rust inside, paint out.	None detected	Rust and bluing of brass fitting in tail wheel.	Plane at Paso Robles during fire season. Steel tank with badly peeled vinyl coating.
E-98	TBM-3	--	B FT	--	Some pit corrosion on structural parts but not on vertical sides of tank.	Some pit corrosion on inside of gates. Some rust.	None detected	None detected	Plane at Oroville during fire season. Plane exterior painted. Tank and gates painted inside and out.

See footnote at end of table.

Table 5.--Corrosion found on aircraft in California, 1964, continued

NON-AIR TANKER AIRCRAFT									
Tanker number	Aircraft type	Retardant[1/]		No. Drops 1964	Corrosion				Remarks
		1963	1964		Tank	Gates	Wings and fuselage	Tail	
SB-BOE	B-17G	--	--	--	--	--	Pit corrosion on under side of wings behind engine exhaust.	None detected	--
--	C-45	--	--	--	--	--	Much pit corrosion on top of fuselage.	None detected	--
N-7228C	B-17G	--	--	--	--	--	Much pitting on most unpainted surfaces including braces inside wings.	Pits on unpainted surfaces.	--
N-79Q	C-45	--	--	--	--	--	None detected	None detected	--

[1/] BO = Borate
B = Bentonite
AG = Algin gel
FT = Fire-trol
PC = Phos-chek
GG = Gelgard

Table 6.--Chemical composition limits of wrought aluminum alloys.[1, 2]

AA DESIGNATION	SILICON	IRON	COPPER	MANGANESE	MAGNESIUM	CHROMIUM	NICKEL	ZINC	TITANIUM	OTHERS③ Each	OTHERS③ Total	ALUMINUM Min. ④
EC⑥			......	......	......	......	......	......	......			99.45
1100	1.0 Si+Fe		0.20	0.05	......	......	......	0.10	......	0.05⑱	0.15	99.00
1130⑦	0.7 Si+Fe		0.20	......	......	......	......			0.05		99.30
1230⑧	0.7 Si+Fe		0.10	0.05	......	......	......	0.10	......	0.05		99.30
1235	0.65 Si+Fe		0.05						......	0.05		99.35
1145⑨	0.55 Si+Fe		0.05	0.05	......	......	......	......	......	0.03		99.45
1345	0.30	0.40	0.10	......	......	......	......			0.05		99.45
1060	0.25	0.35	0.05	0.03	0.03	......	......	0.05	0.03	0.03⑱		99.60
1175⑩	0.15 Si+Fe		0.10	......	......	......	......	......	......	0.02		99.75
2011	0.40	0.7	5.0-6.0	......	......	......	......	0.30	......	0.05⑪	0.15	Remainder
2014	0.50-1.2	1.0	3.9-5.0	0.40-1.2	0.20-0.8	0.10	......	0.25	0.15	0.05⑱	0.15	Remainder
2017	0.8	1.0	3.5-4.5	0.40-1.0	0.20-0.8	0.10	......	0.25	......	0.05	0.15	Remainder
2117	0.8	1.0	2.2-3.0	0.20	0.20-0.50	0.10	......	0.25	......	0.05	0.15	Remainder
2018	0.9	1.0	3.5-4.5	0.20	0.45-0.9	0.10	1.7-2.3	0.25	......	0.05	0.15	Remainder
2218	0.9	1.0	3.5-4.5	0.20	1.2-1.8	0.10	1.7-2.3	0.25	......	0.05	0.15	Remainder
2618	0.25	0.9-1.3	1.9-2.7	......	1.3-1.8	......	0.9-1.2	......	0.04-0.10	0.05	0.15	Remainder
2219	0.20	0.30	5.8-6.8	0.20-0.40	0.02	......	......	0.10	0.02-0.10	0.05⑳	0.15	Remainder
2024	0.50	0.50	3.8-4.9	0.30-0.9	1.2-1.8	0.10	......	0.25	......	0.05	0.15	Remainder
2025	0.50-1.2	1.0	3.9-5.0	0.40-1.2	0.05	0.10	......	0.25	0.15	0.05	0.15	Remainder
3003	0.6	0.7	0.20	1.0-1.5	......	......	......	0.10	......	0.05⑱	0.15	Remainder
3004	0.30	0.7	0.25	1.0-1.5	0.8-1.3	......	......	0.25	......	0.05⑱	0.15	Remainder
4032	11.0-13.5	1.0	0.50-1.3	......	0.8-1.3	0.10	0.50-1.3	0.25	......	0.05	0.15	Remainder
4043	4.5-6.0	0.8	0.30	0.05	0.05	......	......	0.10	0.20	0.05⑱	0.15	Remainder
4343⑫	6.8-8.2	0.8	0.25	0.10	......	......	......	0.20	......	0.05	0.15	Remainder
5005	0.40	0.7	0.20	0.20	0.50-1.1	0.10	......	0.25	......	0.05	0.15	Remainder
5050	0.40	0.7	0.20	0.10	1.0-1.8	0.10	......	0.25	......	0.05⑱	0.15	Remainder
5052	0.45 Si+Fe		0.10	0.10	2.2-2.8	0.15-0.35	......	0.10	......	0.05⑱	0.15	Remainder
5252	0.08	0.10	0.10	0.10	2.2-2.8	......	......	......	......	0.03	0.10	Remainder
5652	0.40 Si+Fe		0.04	0.01	2.2-2.8	0.15-0.35	......	0.10	......	0.05⑱	0.15	Remainder
5154	0.45 Si+Fe		0.10	0.10	3.1-3.9	0.15-0.35	......	0.20	0.20	0.05⑱	0.15	Remainder
5254	0.45 Si+Fe		0.05	0.01	3.1-3.9	0.15-0.35	......	0.20	0.05	0.05⑱	0.15	Remainder
5454	0.40 Si+Fe		0.10	0.50-1.0	2.4-3.0	0.05-0.20	......	0.25	0.20	0.05	0.15	Remainder
5155	0.30	0.7	0.25	0.20-0.6	3.5-5.0	0.05-0.25	......	0.25	0.15	0.05	0.15	Remainder
5056	0.30	0.40	0.10	0.05-0.20	4.5-5.6	0.05-0.20	......	0.10	......	0.05⑱	0.15	Remainder
5356	0.50 Si+Fe		0.10	0.05-0.20	4.5-5.5	0.05-0.20	......	0.10	0.06-0.20	0.05⑱	0.15	Remainder
5456	0.40 Si+Fe		0.10	0.50-1.0	4.7-5.5	0.05-0.20	......	0.25	0.20	0.05	0.15	Remainder
5257	0.08	0.10	0.10	0.03	0.20-0.6	......	......	0.03	......	0.02	0.05	Remainder
5457	0.08	0.10	0.20	0.15-0.45	0.8-1.2	......	......	......	......	0.03	0.10	Remainder
5557	0.10	0.12	0.15	0.10-0.40	0.40-0.8	......	......	......	......	0.03	0.10	Remainder
5657	0.08	0.10	0.10	0.03	0.6-1.0	......	......	0.03	......	0.02	0.05	Remainder
5083	0.40	0.40	0.10	0.30-1.0	4.0-4.9	0.05-0.25	......	0.25	0.15	0.05	0.15	Remainder
5086	0.40	0.50	0.10	0.20-0.7	3.5-4.5	0.05-0.25	......	0.25	0.15	0.05	0.15	Remainder
6101⑬	0.30-0.7	0.50	0.10	0.03	0.35-0.8	0.03	......	0.10	......	0.03⑲	0.10	Remainder
6201	0.50-0.9	0.50	0.10	0.03	0.6-0.9	0.03	......	0.10	......	0.03⑲	0.10	Remainder
6003⑭	0.35-1.0	0.6	0.10	0.8	0.8-1.5	0.35	......	0.20	0.10	0.05	0.15	Remainder
6011	0.6-1.2	1.0	0.40-0.9	0.8	0.6-1.2	0.30	0.20	1.5	0.20	0.05	0.15	Remainder
6151	0.6-1.2	1.0	0.35	0.20	0.45-0.8	0.15-0.35	......	0.25	0.15	0.05	0.15	Remainder
6951	0.20-0.50	0.8	0.15-0.40	0.10	0.40-0.8	......	......	0.20	......	0.05	0.15	Remainder
6053	⑰	0.35	0.10	......	1.1-1.4	0.15-0.35	......	0.10	......	0.05	0.15	Remainder
6253⑮	⑰	0.50	0.10	......	1.0-1.5	0.15-0.35	......	1.6-2.4	......	0.05	0.15	Remainder
6061	0.40-0.8	0.7	0.15-0.40	0.15	0.8-1.2	0.15-0.35	......	0.25	0.15	0.05	0.15	Remainder
6062	0.40-0.8	0.7	0.15-0.40	0.15	0.8-1.2	0.04-0.14	......	0.25	0.15	0.05	0.15	Remainder
6262	0.40-0.8	0.7	0.15-0.40	0.15	0.8-1.2	0.04-0.14	......	0.25	0.15	0.05⑤	0.15	Remainder
6063	0.20-0.6	0.35	0.10	0.10	0.45-0.9	0.10	......	0.10	0.10	0.05	0.15	Remainder
6463	0.20-0.6	0.15	0.20	0.05	0.45-0.9	......	......	......	......	0.05	0.15	Remainder
6066	0.9-1.8	0.50	0.7-1.2	0.6-1.1	0.8-1.4	0.40	......	0.25	0.20	0.05	0.15	Remainder
7001	0.35	0.40	1.6-2.6	0.20	2.6-3.4	0.18-0.40	......	6.8-8.0	0.20	0.05	0.15	Remainder
7039	0.30	0.40	0.10	0.10-0.40	2.3-3.3	0.15-0.25	......	3.5-4.5	0.10	0.05	0.15	Remainder
7072⑯	0.7 Si+Fe		0.10	0.10	0.10	......	......	0.8-1.3	......	0.05	0.15	Remainder
7075	0.50	0.7	1.2-2.0	0.30	2.1-2.9	0.18-0.40	......	5.1-6.1	0.20	0.05	0.15	Remainder
7076	0.40	0.6	0.30-1.0	0.30-0.8	1.2-2.0	......	......	7.0-8.0	0.20	0.05	0.15	Remainder
7277	0.50	0.7	0.8-1.7	......	1.7-2.3	0.18-0.35	......	3.7-4.3	0.10	0.05	0.15	Remainder
7178	0.50	0.7	1.6-2.4	0.30	2.4-3.1	0.18-0.40	......	6.3-7.3	0.20	0.05	0.15	Remainder
7079	0.30	0.40	0.40-0.8	0.10-0.30	2.9-3.7	0.10-0.25	......	3.8-4.8	0.10	0.05	0.15	Remainder

①*Composition in percent maximum unless shown as a range.*

②*For purposes of determining conformance to these limits, an observed value or a calculated value obtained from analysis is rounded off to the nearest unit in the last right-hand place of figures used in expressing the specified limit, in accordance with American Standard Rules for Rounding Off Numerical Values (ASA Z25.1).*

③*Analysis is regularly made only for the elements for which specific limits are shown, except for unalloyed aluminum. If, however, the presence of other elements is suspected, or indicated in the course of routine analysis, further analysis is made to determine that these other elements are not in excess of the amount specified.*

④*The aluminum content for unalloyed aluminum not made by a refining process is the difference between 100.000 percent and the sum of all other metallic elements present in amounts of 0.010 percent or more each, expressed to the second decimal.*

⑤*Also contains 0.40-0.7 per cent each of lead and bismuth.*

⑥*Electric conductor.* ⑦*Reflector sheet.*

⑧*Cladding on alclad 2024.* ⑨*Foil.*

⑩*Cladding on clad 1100 and clad 3003 reflector sheet.*

⑪*Also contains 0.20-0.6 percent each of lead and bismuth.*

⑫*Brazing alloy.* ⑬*Bus conductor.*

⑭*Cladding on alclad 2014.*

⑮*Cladding on alclad 5056.*

⑯*Cladding on alclad 2219, 3003, 3004, 5050, 5155, 6061, 7075, 7178 and 7079.*

⑰*Silicon 45 to 65 percent of magnesium content.*

⑱*Beryllium 0.0008 maximum for welding electrode and filler wire only.*

⑲*Boron, 0.06 percent maximum.*

⑳*Vanadium 0.05-0.15; zirconium 0.10-0.25.*

Source: Standards for aluminum mill products. The Aluminum Association, New York, N.Y., October 1964.

Table 7.--Components of clad products.

DESIGNATION	COMPONENT ALLOYS ① CORE	COMPONENT ALLOYS ① CLADDING	TOTAL THICKNESS OF COMPOSITE PRODUCT Inches	SIDES CLAD	NOMINAL CLADDING THICKNESS PER SIDE ② Percent of Composite Thickness
Alclad 2014 Sheet and plate	2014	6003	Up thru 0.024	Both	10
			0.025-0.039	Both	7½
			0.040-0.099	Both	5
			0.100 and over	Both	2½
Alclad 2219 Sheet and plate	2219	7072	Under 0.040	Both	10
			0.040-0.099	Both	5
			0.100 and over	Both	2½
Alclad 2024 Sheet and plate	2024	1230	Up thru 0.062	Both	5
			0.063-0.187	Both	2½
			0.188 and over	Both	1½, 2½ ③ ④
Alclad 3003 Sheet and plate	3003	7072	All	One or Both	5
Alclad 3003 Tube	3003	7072	All	Inside	10
			All	Outside	7
Alclad 3004 Sheet and plate	3004	7072	All	Both	5
Alclad 5050 Sheet and plate	5050	7072	All	Both	5
Alclad 5155 Sheet and plate	5155	7072	All	Both	5
Alclad 5056 Rod and wire	5056	6253	All	Outside	20% of total cross-sectional area.
Alclad 6061 Sheet and plate	6061	7072	All	Both	5
Alclad 7075 Sheet and plate	7075	7072	Up thru 0.062	Both	4
			0.063-0.187	Both	2½
			0.188 and over	Both	1½ ④
Alclad One Side 7075 Sheet and plate	7075	7072	Up thru 0.062	One	4
			0.063-0.187	One	2½
			0.188 and over	One	1½ ④
Alclad 7178 Sheet and plate	7178	7072	All	Both	4
Alclad 7079 Sheet	7079	7072	Up thru 0.062	Both	4
			0.063-0.187	Both	2½
			0.188 and over	Both	1½
No. 11 Brazing sheet	3003	4343	Up thru 0.063	One	10
			0.064 and over	One	5
No. 12 Brazing sheet	3003	4343	Up thru 0.063	Both	10
			0.064 and over	Both	5
No. 21 Brazing sheet	6951	4343	Up thru 0.090	One	10
			0.091 and over	One	5
No. 22 Brazing sheet	6951	4343	Up thru 0.090	Both	10
			0.091 and over	Both	5
Clad 1100 Reflector sheet	1100	1175	Up thru 0.064	One or Both	15
			0.065 and over		7½
Clad 3003 Reflector sheet	3003	1175	Up thru 0.064	One or Both	15
			0.065 and over		7½

①Cladding composition is applicable only to the aluminum or aluminum alloy bonded to the alloy ingot or slab preparatory to rolling to the specified composite product. The composition of the cladding may be subsequently altered by diffusion between the core and cladding due to thermal treatment.

②Average minimum thickness of cladding per side after rolling to the specified thickness of sheet and plate will be 80 percent of the nominal cladding thickness as determined by averaging cladding thickness measurements taken at a magnification of 100 diameters on the cross section of a transverse sample polished and etched for microscopic examination.

③Alclad 2024 sheet and plate in thicknesses of 0.188 inch and over are furnished with a nominal cladding thickness of 2½ percent unless the thinner cladding is specifically designated.

④For thicknesses of 0.500 inch and over with 1½ percent nominal cladding thickness, the average maximum thickness of cladding per side after rolling to the specified thickness of plate will be 3 percent of the thickness of the plate as determined by averaging cladding thickness measurements taken at a magnification of 100 diameters on the cross section of a transverse sample polished and etched for microscopic examination.

Source: Standards for aluminum mill products. The Aluminum Association, New York, N.Y., October 1964.