INSULATED ALUMINUM PANELS FOR DRY KILN WALLS AND ROOFS

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Many of the limitations of building life and dry kiln performance have in the past, been the result of the process conditions of kiln drying. These conditions are far from normal. It may not be generally realized, but in the Western region the effects of rain and snow on the building are relatively unimportant when compared with the amount of water that comes from the inside. A dry kiln building should be constructed with this in mind. Normal building design methods do not apply.

High moisture content is a very damaging factor in kiln performance and maintenance. Moisture carriers destructive agents from kiln vapors to damage mortar joints in kiln buildings. Moisture enters structural concrete to rust the iron reinforcing rods. It both corrodes and erodes metal parts elsewhere in the kilns.

Most damaging of all, are its effects on wooden buildings. In fact, water combined with high kiln temperatures create many serious problems. Water in excess, where-ever found, is the number one culprit, and construction methods in general use, do little to remedy the situation.

Lets Consider the Source of Moisture

Try to imagine the tropical hurricane that is formed inside of a dry kiln. The weather inside of the building is far more severe most of the time than on the outside. Weather in this case is hot and humid. In most kiln buildings the best moisture barrier is placed on the outside to keep weather out but, oddly enough, the amount of water which falls as rain or snow from without is actually very small compared to that which is present most of the time during the drying of lumber. It would seem logical, then, to keep the water out of the walls and roof by using the best possible inner barrier and to allow that which creeps through, to escape freely to the outside. Instead, the inside is generally painted with a standard coating when the kiln is built, and on top of the roof is laid a much better moisture barrier, a wooden 3-layer built-up roof with felt or asphalt to keep out the rain and snow. It does this, all right, but at the same time much of the water that comes through the inner coating in the form of vapor is contained within the roof. The walls, which have no built-up outer moisture barrier, are not affected but the roof eventually becomes loaded with water. Tests show the moisture content in the roof may be 150 per cent and higher. There may be so much water under this outer roof covering that when punctured the water spurts out like a miniature geyser.

What actually causes this? The answer is simple. Tests using all classes of coating show that no perfect vapor barrier is available. A small amount of water vapor constantly passing through the inner coating travels through the wall or ceiling until it comes in contact with the cooler zone near the surface. At this point, the vapor condenses into the form of liquid water. If no outer vapor barrier were present, it could pass on out by evaporation at the surface. This happens at most outer walls. But on the roof with its good 3-layer barrier, very little water can escape.

How Does This Effect on Kiln Life?

As we have said before, the water and the high temperature work together to shorten kiln life. Wooden kiln roofs seldom last more than 6-8 years. The walls may outlast two roofs. They do not have an outer vapor barrier and so are drier. Concrete is thought to be everlasting. This may not be true when water condenses on the reinforcing rods and corrodes them.

The effect of the corrosion is two-fold. First, rust breaks the mechanical bond between the rod and the concrete. This weakens the strength in tension supplied by the rods. Second, the rods actually grow in size as the rust forms on them, because the iron oxide occupies more space than the iron it replaces. This enlargement continues as the coating thickens, eventually exerting force enough to break the surrounding concrete, causing it to spill away. The damage is sometimes great enough to cause complete roof failure. The damage to wooden roofs, although different in nature may be equally severe.

What is the Effect on Insulation?

Water also decreases the insulating value of building materials. This is important because heat losses increase drying costs. Concrete roofs are generally insulated, because concrete is a poor insulating material. Lightweight aggregate is commonly used.

These buildings need to be caulked, or sealed to reduce losses, and help maintain the correct environment around the lumber. They need coating for protection against corrosive wood acids. Maintenance and repair work are not too drastic when kiln schedules are in 135-175^{o} F. range. With the advent of high temperature drying, caulking and coating of necessity became an annual or more often affair.

If heat losses are high, airflow and temperature distribution within the building are usually poor. This prompted the thought why not design a complete package unit, with a minimum of heat loss, easily erected and maintained, free from the multi contractor headaches. This was the birth of the prefabricated kiln.

When looking for a material readily fabricated into modular panels providing a structure with; good appearance, easily erected, reduced maintenance characteristics, long life, aluminum was picked from a multitude of metals available.

What Are the General Properties of Aluminum?

It is very light metal with a density of 2.7 grms/cc, approximately 0.1 lb/cu. in. This makes it about a 1/3 as heavy as copper or steel. This light weight metal and its alloys possess a good strength, to weight ratio. This effect is best known through strength-requiring applications; like highway transportation equipment and aircraft; where pay load can be increased without sacrificing strength or safety features. The factor stressed in any comparison with all forms of steel is the weight involved with equal thickness, strength or stiffness.

For kiln components it allows easy workshop handling of large sheets of material in insulated panel preparation. These, together with extrusions, are easily formed, cut, punched, riveted or welded. The pre-formed lightweight items gain some advantages in freight costs from the manufacturers plant to the mill. At the job site installation personnel appreciate the large panels and lightweight connecting extrusions which can quickly, be erected around the support framework, with less sweat and toil.

Aluminum is both a good thermal conductor and a good reflector of radiant heat. It may at first seem strange that we select a material with these characteristics for a kiln. We wish to maintain a set temperature condition within the building and yet we use materials conductive to high heat losses. However the insulated panel skin of 0.024" material is backed by 1-1/2" of fiberglass insulation; which has excellent insulation value, as shown on following table. This effectively reduces heat conducted (lost) through the skin to an acceptable level.

Table 1. Insulation Comparison Chart

MATERIAL	CONDUCTIVITY "k"	RESISTANCE "R"	THICKNESS Inches
Glass Wool or Fiberglass	0.27	3.70	1.5
Structural Wood Fiber (20 lbs./ft.3)	0.38	2.63	2.4
Perlite (expanded)	0.38	2.63	2.4
Vermiculite (expanded)	0.48	2.08	3.0
Fiberboard 25/32"		2.06	3.0
Concrete (expanded shale aggregate)	0.90	1.11	5.5
Wood (across the grain)	0.65-0.1.15	0.15-0.87	4.0-7.25
Wood (parallel to grain)	1/6-2.9	0.625-0.335	10.0-18.5

Table 1. Continued

MATERIAL	CONDUCTIVITY "k"	RESISTANCE "R"	THICKNESS Inches
1" nominal lumber (accepted Industry Standard)	1.02	0.98	6.4
Asbestos "T" Deck	4.0	0.25	25.0
Common Building Brick	4.9	0.205	30.0
Concrete (sand and gravel aggregate)	12.0	0.08	78.0

"k" = thermal conductivity in BTU/Hr. Sq. Ft. / ^{O}F. inch thickness
"R" = resistivity or resistance to heat transmission $R = \frac{1}{K}$

The heavier gauge extrusions and battens used to interlock the panel system contribute to the heat losses. These more solid strips of aluminum are bolted together at frequent intervals to maintain a leak-free insulated shell. Heat is conducted through the thick extrusions, particularly where an interconnecting bolt occurs. However, the 1-1/2" air gap helps reduce this loss. Running the hand across a panel will highlight the gradation in temperature experienced from the extrusion to the better insulated panel section. Latest panel design had reduced this space between panels to minimum.

Radiant energy is transmitted through space as waves. When absorbed the radiant energy increases the temperature of the absorbing body. Being a good reflector aluminum rejects this heating effect. It therefore rejects back into the kiln any radiant energy attempting to escape. This energy reflection markedly cuts down heat losses. On the outside of the kiln sunlight or solar energy is likewise reflected by the polished silver skin. This explains how an aluminum roof makes a building cooler in summer. It reflects a high percentage of solar heat and only a small percentage of what is absorbed is re-radiated to the interior.

This reflectivity shows up in another sense. It can be "dazzling" in a very real and annoying manner. The glare of light reflected from an aluminum structure can be compared to that from snow or the surface of water.

To overcome this unpleasantness embossed finishes were introduced. In addition to enhancing design or appearance characteristics, embossing increases stiffness over standard flat sheet and diffuses incident light. Embossing is only one method of softening glare to a tolerable level. Coatings and other surface treatments can be applied to achieve the same effect; they also increase the corrosion resistance of the parent material.

Aluminum has a high coefficient of linear expansion compared to most other common metals. Some values at ambient conditions are:

Table 2

Zinc	15.2×10^{-6}
Aluminum	15.0×10^{-6}
Brass	10.5×10^{-6}
Copper	9.5×10^{-6}
Iron	6.65×10^{-6}
Steel	6.1×10^{-6}

This factor must be considered in the design of a building which may fluctuate in temperature from -50^{O}F. to +240^{O}F.; particularly where aluminum is joined in some manner to other materials of lower expansion characteristics.

Consider the interlocking extrusions; a 12' - 13' length of this material in a kiln operating at 240-250°F. will expand approximately 1/2"; an outside temperature of -50°F. would cause a similar length to contract over 1/4".

Aluminum and its alloys were at one time difficult to weld reliably. The surface oxide film and the good thermal and electrical conductivity were the main reasons for this problem.

Generally the oxide film is one of the desirable features of the metal. In welding, however, it is necessary to eliminate its effect. It can be dissolved away by a flux or scraped so thin that it breaks up during welding. The real advance was the introduction of inert gas-arc welding. The action of the arc removes the oxide film and the inert gas blanket (argon or helium) prevents re-formation until weld fusion is complete.

Introducing the inert gas welding technique allows sound reliable welds to be produced economically. No flux is used so there is no problem of corrosion by flux residue. The weld and associated area is heat treated so it does not denude the adjacent area of components; a joint is produced which is free from embrittlement, crackling, and does not usually suffer, stress, or other special corrosion problems.

These are some of the general, or physical properties of the material. The outstanding feature, which makes aluminum or its alloys suitable for dry kiln components is its resistance to corrosion.

To examine this in a little more detail we should consider:

(1) How does aluminum have this resistance?
(2) What gives rise to the corrosive atmosphere in a dry kiln?

General remarks on both these topics alter depending on the drying conditions, species, special wood treatments, plant location and methods of assembly. The best indication of aluminum versatility is provided by citing some of the specific problems encountered.

<u>First Lets Consider the Corrosion Resistance of Aluminum</u>

Resistance to corrosion is a relative matter because it depends on the environment to which it is exposed. In a general sense, corrosion is the process by which a metal reverts to its ore when exposed to natural weathering or the action of more aggressive atmospheres.

Aluminum and its alloys have exhibited excellent resistance to corrosion in a wide variety of service applications. It is attributed to two properties:

(1) The nature of the air-formed surface oxide film.
(2) The semi-protective nature of the corrosion products formed at breaks in this film.

The film is thin, initially about one millionth of an inch thick growing to an equilibrium value of about five millionths thick in a short time interval.

It is variously described as tough, adherent, non-flaking, or non-progressive, non-porous and self-renewing.

Film adhesion is excellent because it is chemically bonded to the base metal. The toughness (to remove, break or penetrate) comes from the fact the film is formed under compression. Aluminum oxide has a slightly larger specific volume than aluminum, films are consequently formed in compression. This means good compaction, dense film with low porosity or permeability. Permeation can be oxygen or other agents from outside attempting to get through the film to the metal, or metal diffusing outwards to the film interface. With aluminum outward metal diffusion occurs.

The nature of the film is such that it is highly protective if kept in a state of repair. In most instances the corrosive environment contains air. Under mildly corrosive conditions oxygen from the air will heal ruptures in the film.

If the corrosive media is such that film repair is difficult, corrosion will start at discontinuities or thin points in the air formed film. The precipitate (or corrosion product) formed is generally believed to add additional protection by reducing the rate of diffusion of dissolved aluminum to the outer surface. In this respect aluminum corrosion products impose a greater resistance to the diffusion or permeation of ions than corrosion products formed on other metals. It is this combination of protective air-formed oxide film and relatively protective corrosion products that leads to the good resistance of aluminum alloys to most corrosive environments.

Should unusually severe conditions arise, resistance can be augmented by several methods.

(1) Anodising the surface - This is the electrolytic formation on the metal of an oxide film which is relatively thick compared to the natural oxide film. Some anodising processes reduce the porosity of the oxide film even further.

(2) Select another aluminum alloy - Pure 99.99% aluminum is not the material in general use, they are
3000 series - alloys containing around 1.5% maganese
6000 series - alloys containing 4% magnesium and some silicone

There are eight series of alloys from which to choose. Often the addition of a specific alloying agent can assist with a particular corrosive condition.

(3) Cladding of the sheets - By this method the original or core material is faced with a thin, rolled on film of another aluminum alloy. If the core material should become exposed the "cladding" coat will corrode sacrifically to protect the core. It works on the principle of cathodic protection.

(4) Paint or coat the material - For best results the coating should be applied at the rolling mill. In this way they can properly clean, prime and apply the alkyd or acrylic enamel.

All these approaches will help; the one offering the greatest degree of assistance is the rolling mill applied coating or #4.

However for normal dry kiln use, the present used alloys have been satisfactory, without additives.

To expand on corrosive factors inside dry kilns, the following gives a better description of Dry Kiln Corrosive atmosphere.

Wood is mainly composed of celluslose (70%), lignin (20-30%), and extractives. Other descriptions break it down into simpler terms such as carbohydrates, (sugars and starches), lignin, oleoresins, (oils and resin), some fats and waxes, tannins and coloring matter, water (or better, sap which contains salts and nutrients) and organic acids.

In the heat and humidity of a dry kiln, portions of this heterogeneous mixture breakdown, there is a slow hydrolysis of part of the carbohydrate to "wood acids." Others describe it as a fermentation of the sugars and starches to produce acid by-products. Have you ever detected the smell of a brewery of distillery or a sour vinegar odor among drying lumber? Whatever the reaction or mechanism, volatile acids are produced, the commonly recognized members are formic, acetic and carbonic acid.

These acid products are picked up in the circulating air stream and give rise to the corrosive environment encountered inside a kiln. You probably realize that the higher the operating temperature in the kiln (for shorter schedules) the faster the breakdown occurs. More acids are produced in a shorter space of time, so concentration could be higher.

I believe a fuller explanation of some of the terms and reactions occuring may help you understand what goes on in your kiln.

Acidity is gauged by the pH of the system. The pH scale extends from 1 to 14; 7 is the neutral point in the scale (generally corresponds to the pH of water). On the acid side we have:

Table 3

pH - 7.00 = neutral
pH - 5.00 = weakly acidic
pH - 3.00 = acidic
pH - 1.00 = strongly acidic

The rate of acidic product liberation depends upon the chemical constitution of the wood components from which it is derived. This differs from species to species. The proportion of components capable of giving rise to acetic acid (vinegar) is higher in hardwood (3-5%) than in softwoods (1-2%).

Heartwood is made up of inactive cells, older material in which is deposited resins, gums, phlobaphenes, tannins and other secretions. You can imagine how part of this accumulation will break down, steam distill, or exude from the wood under the heat and humidity of a kiln.

Sapwood contains living cells. This is younger material which contains more free sugars or nutrients and oleoresins in species having resin canals. Heat applied in the dry kiln process will break down the sugars and bring much of the oleoresins to the surface. At the wood surface, volatile constituents evaporate (turpentine and like materials), leaving a coating of resin removed by subsequent surfacing.

This resinous or non-resinous nature of the wood can be important in an aluminum kiln. A kiln drying Douglas fir or Pine will in time become coated by a varnish or shellac-like layer distilled from the wood. It forms an extra protective layer on the walls.

Kilns drying Western Hemlock, which is non-resinous, do not build up this protective layer. Its more acidic vapors attach the kiln walls directly.

Tests have been made collecting the vapors, issuing from the dry kilns, handling different species, In one case, the Vancouver Forest Products Lab compared the condensate from Hemlock and Douglas fir over a 4-day cycle.

Table 4

Day	Hemlock pH of Condensate	Douglas Fir pH of Condensate	
2nd	4.06	4.16	
3rd	3.80	4.01	
4th	3.65	4.00	Acidity Increasing
	3.58		
	3.54	4.00	

We have collected condensate from kilns drying Ponderosa pine and some fir and larch. Again the pH went to 3.5 - 3.75 in the latter stages.

In both these instances material was collected under conditions of efficient condensation, (glass and copper condensers). Inside a dry kiln, condensate forms in all kinds of congested areas, particularly at bolt or nail heads, around vent bases and any area where the dew point occurs. Under these conditions it could be more concentrated and much more acidic than the values shown.

Having heard the frightening affect temperature and humidity has on wood components you may well ask, "how did the old dry kiln last so long? how does aluminum manage to withstand the onslaught now?"

The answer probably lies in the kiln drying conditions and the pace of operation. When maximum operating temperatures were in the 150° F. to 175° F. range, and annual shutdowns with adequate time for repainting and repair were available, wood, block, concrete, and steel, etc. did not deteriorate so rapidly. As operating conditions pushed upwards and the demand increased, less time and attention is paid or is available for repairs. The threshold temperature is probably around 200° F. At or above this level the previously adequate materials are found impractical in many respects. Adequate repair and maintenance work is essential. Downtime for repairs means lost production, repairs are now more costly. Both factors work against allocation of adequate repair time.

Aluminum can withstand the temperatures, combat the acid environment and is impermeable to water or water vapor. Possibly the best way to describe its adequacy or versatility is to consider some examples of kiln problems.

1. Would Be Typical West Coast Wood Applications

Aluminum kilns are already in use in the drying of: Douglas fir, Sikta spruce, Western Hemlock, Western Red Cedar, California Red and White Fir, Lodgepole, Ponderosa and Sugar Pine.

The low pH or acidity that can be encountered in Hemlock and Douglas fir units has been mentioned.

In 1963 the Aluminum Development Association and the Forest Products Research Lab in Britain assessed the corrosion of aluminum and some alloys in contact with various woods. Some pH values recorded in their work may serve as a guide to what we could expect in units drying these species.

Table 5

Timber	pH Value or Acidity in Wood
Western Red Cedar	3.3 - 3.5 (2.9 - 4.0)
Sitkas Spruce	3.35 - 4.0
Douglas Fir	3.1 - 4.4
Larch	4.0 - 4.9
Western Hemlock	4.8
Redwood	4.75 - 5.25
Oak	3.3 - 3.9

This cross section of the woods tested show that some severe conditions can be generated in a kiln. It is quite rare to find only one species dried in a kiln. The tendency is for some deposit to build up on the face of the aluminum. This assists in the protection of the metal when drying the likes of Hemlock or Western Red Cedar.

2. Another Application is in the Use of Direct Fired Heating Systems

With the presence of oxygen so important for oxide film maintenance and repair it may appear that the products of combustion would present a problem. Although a greater proportion of Carbon Dioxide is present in the air stream, there is sufficient excess air and changes of air in the system to provide adequate oxygen.

Even if the gas or oil fired system were to contain a relatively high proportion of sulphur components it would not seriously affect the aluminum. The sulphur oxides produced on combustion will form acid products in the humid environment. The worry is more for the steel framework. The same is true when the more aciditic woods are being dried (Hemlock, Cedar, etc.). The steelwork needs to be well protected and kept this way to avoid serious corrosion.

3. Siting an Aluminum Kiln Near the Coast

In this case the worry is over the outer skin deteriorating in a marine environment. Salts in the spray carried by onshore winds can have a serious effect on aluminum.

Here we meet a substance which can penetrate the aluminum defense mechanism. Sea salts contain chlorine and the chloride ion is small enough to penetrate the oxide film. This can lead to a pitting type corrosion.

Fortunately, the salt crust or deposit needs to be in contact some time before penetration and breakdown of the film occur. Flushing with fresh water will overcome this type of problem. Normally in most areas a good shower of rain will suffice.

The aluminum manufacturers do run into odd problems with this situation where there is little or no rain. In the Crescent City area for example there are some plant structures with aluminum. Due to a rain shadow effect the salt deposit is not washed away frequently enough (about every 3-4 weeks). In a situation like this they recommend hosing down with water every month.

Sea-borne logs or the old salt seasoned lumber would give rise to the same type problems inside the kiln. These occur rarely now-a-days.

If a marine environment problem like this is recognized before construction, you may take advantage of selecting a more resistant alloy, anodizing or coating. In this instance if extra protection is desired, a coating gives long term durability.

4. Drying Incense Cedar

Seasoning of incense cedar itself does not create a very acidic atmosphere in the kiln. Where pencil slats are being produced, the wood is stained. These stains are generally aniline dyes which are acidic. Aluminum components immersed in the stain liquor have been found to corrode, and disintegrate. Will the same thing occur in aluminum dry kiln components? It is not considered likely. The stains tend to become fixed to the wood fibers. They are water soluble and therefore capable of moving to the surface of the slats under drying conditions. There should be little or no carry over however of the stains, or breakdown products from these complex dyes, into the circulating air stream.

We have tested sections of 3000 and 6000 series aluminum in and above baths of wood acids treated with stain for some months without any deterioration.

5. Fire Retardent of Other Treated Woods

Here a chemical treatment of impregnation is imposed on the wood. When drying, will it give rise to special problems.

Fire retardent treatment adds such chemicals as ammonium sulphate, ammonium phosphate, borax or boric acid, zinc chloride, sodium arsenate. These chemicals are again water soluble and can migrate to the surface under drying. Ammonium slats can be hydrolyzed to produce free ammonia.

Little or no salts should be transferred to the metal surfaces. Aluminum has a mixed reaction with ammonia, at some concentrations and temperatures it is satisfactory, others not so successful. In this case the free ammonia does not last long and may be removed by mild air drying or it will quickly be neutralized as wood acids are generated during seasoning.

Other wood treatments encountered are of the preservative type. Impregnation with creosote, fluoride-chrome-arsentate, copper-chrome-arsenate, copper naphthenate.

Aluminum is known to be sensitive to heavy metals such as mercury, lead and copper. So care must be taken to handle the treated products correctly after impregnation. If aggressive mixtures were to be used it would probably be best to use coated aluminum.

Often we are asked about coating parts of an aluminum kiln with asphalt or butuminous coatings. Generally paints or coatings with a bituminous base can be used over aluminum sheet. (By adding a black coating however much of the reflectivity effect is lost.) On occasions the inert filler used in heavy coatings has been treated with a bactericide containing mercury, lead or copper. If treated fillers or salts of this nature are added, avoid the use of the coating.

We do not believe aluminum panels that are properly constructed will need any of this type of coating, for normal kiln use. Sometimes in the early designed aluminum kilns, a poor grade of insulation was used. The insulation gathered the condensate and held it inside the panel. This caused a continuous saturation of high acidity moisture. If this condition exists, the panel should be drained to remove the acid condition.

This is why Moore Oregon panels are constructed to allow condensate to flow from the panels, even though fiberglass will not absorb water. This is also the reason we are reluctant to construct flat-roof pre-fabricated aluminum kilns.

The following pictures will illustrate the practical use of pre-fab aluminum panels in both building wall and roof construction.

We are Moore Oregon have now established a design of pre-fab aluminum panels for roof replacement. This application is principally for replacement of wood roofs of pitched or slope design.

We would appreciate the opportunity of discussing this further with you for your particular application.