DURABILITY PERFORMANCE OF COATED METAL ROOF AND WALL CLADDING

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Sheet metal roof and wall claddings were among the vast array of new products spawned in the industrial revolution of the nineteenth century. The light weight and robust nature of galvanized steel cladding, in particular, encouraged its use in even the remotest of locations. In rural Australia, notably in arid areas where timber was scarce, no building material has been more successful and better identified with the Australian landscape. In cities and towns a century ago, painted and unpainted metal roofs and painted pressed metal ceilings were commonplace.

Galvanized structures remain a feature of the Australian rural landscape as typified by this tank and windmill.

In recent years, a range of more durable decorative paint systems for sheet metal, the development of a range of composite cladding systems and sophisticated building designs and an increased popularity of earlier architectural styles has seen a resurgence in use of metal sheet as a construction material for buildings. It is also notable that, where metal roofing and cladding were regarded as a mundane construction materials until a few decades ago, they have now extended to the prestige end of the market, particularly with the development of unpainted and painted aluminum and stainless steel claddings.

The central message of this article extols the benefits of contemporary factory coated claddings and discusses the range of products available, including the durability and aesthetic qualities. However, as with any new initiatives with manufactured products, there are inevitable teething problems, while manufacturers, designers and builders develop an appreciation of the advantages and limitations of each of change. This article identifies some of the problem areas and how these might be minimized or avoided.

BARE GALVANIZED AND ZINC/ ALUMINUM ALLOY COATED STEEL

Galvanizing has been a most significant and forgiving protective coating for steel cladding for over 100 years. In 1972, a 55% aluminum/zinc alloy coating (Galvalume) was introduced to the American market to largely supersede galvanizing for roof and wall cladding, with a similar product (Zincalume) introduced to the Australasian market in 1979. A 95% zinc 5% aluminum alloy coated (Galfan) was introduced to the international market five years later[1,2].

The growth in the use of metal cladding through the 1980s was remarkable, particularly for roofing, where much of it is prepainted. For example, in Europe the market share for pre-painted steel increased from 15% in 1976 to 80% by 1988[3]. This has occurred mainly at the expense of flat built up roofs and fibrous cement products. In Australia, 35% of residential roofing is now 55% Al-Zn coated steel, mostly prepainted[4].

The durability performance of galvanized and zinc/ aluminum alloy coated steel cladding in any one situation is essentially governed by the coating thickness. A limited range of coating thicknesses are available, but for general use the thickness of zinc coating in each instance is typically around 20 micrometers.

The durability of these products is well established. Work by Horton[5] indicates that the corrosion rate of the 55% aluminum/zinc alloy coated product in the general atmosphere is two or three times slower than the same thickness galvanizing while King[6] indicates that in severe coastal service galvanizing is even more vulnerable. The 5% aluminum alloy product performance lies in between the two[7]. The most important limitations of these materials are their poor resistance to alkalis and acids, severe marine environments and some specific materials such as copper salts, and in the case of zinc/aluminum coatings, lead.

Pure zinc has also been used from time to time as roofing and for rainwater goods, but generally only on older buildings of historic significance where extra long life is demanded.

PAINTED METAL SHEETING

The demand for prepainted metal cladding over the last two decades has been encouraged by a proliferation of coating types, profiles, colors and embossed and textured finishes and with some imaginative architectural applications[8].

The overwhelming majority of new painted metal sheeting is factory precoated and for good reason. It is, on balance, a far more reliable product than that painted in the field, with optimum conditions for surface preparation, application and curing being much more easily achieved than can be mirrored in the field. Indeed, the presence of forming oils, wet storage staining and dirt variously can make field painting difficult. Economies of scale also ensure that precoated cladding is usually more cost effective.

There are fundamentally two different philosophies in factory precoating, decorative and protective functions[3,4,5,6,9].

Decorative Coatings

These organic coatings (coil coatings) are usually some 20 micrometers thick and are essentially intended to provide the requisite colour and gloss. The coatings are typically polyesters and silicone polyesters or, for maximized gloss and colour retention and resistance to chalking, polyvinylidene difluoride types (PVF_2).

The coating system does not rely on a continuous film to provide the requisite service life and bare cut edges and minor scratches to the zinc rich metal do not significantly impair sheet durability. Indeed, at sharp bends in the profile it is common to expect fine microscopic cracks in the organic coating. These detract little from long term performance. Further, although coil coatings over zinc coated steel provide some synergistic increase in the life of the metal, at least in locations away from the coast, because the demise of most structures ultimately occurs at localized areas, such as the uncoated obverse of the sheet or at a fastener, the additional coating has little influence on life.

The time to maintenance painting of these decorative coatings is largely influenced by the building owner's perceptions. For the traditional silicon modified polyesters typically might begin to chalk significantly and lose gloss after about 8-10 years in temperate outdoor exposure, however the substrate metal could still remain protected for some 20 years. For PVF_2 types a much longer service life should be anticipated.

Protective Coatings

These coatings systems are usually required to also provide the requisite colour and gloss, however, unlike the decorative systems discussed above, they are designed to greatly enhance service life and permit cladding use a more aggressive environment than possible with the essentially decorative coatings on steel sheeting.

The organic coating systems are much thicker, typically 70 - 150 micrometers or more, in order to provide a continuous barrier coating over the sheet profile. In designing the structure, it will usually be necessary for cut edges of the metal to be coated or the building designed such that these edges are buried in sealant or profiled so as to be located in the benign environment of the wall cavity.

Such coatings are not new. A notable early product was an asbestos filled bituminous coated galvanized product. It was used widely for industrial roofing and boasts a service life over 40 years even in quite severe industrial situations, such as the protection of power station roofs from acidic fallout. Contemporary products are usually a three or more coat system, typically an etch prime base coat, an intermediate epoxy barrier and a decorative finish coat, usually a polyvinylidene difluoride (PVF_2) type. Plasticized PVC film bonded to the steel sheet has also been most successful.

In practical terms their durability performance is largely dictated by the effectiveness of the building design and construction in sealing cut edges and in maintaining the integrity of the building fabric. It is however reasonable to expect a life of many decades for these products in most conditions of atmospheric service.

Composite Panels

Composite factory assembled metal building panels have grown in popularity in recent years. They are sandwich panels consisting of two sheet metal panels interleaved by a variety of infills. Infills variously include polystyrene and polyurethane foam, polyethylene and expanded aluminum mesh.

PRODUCTION PROBLEMS

In the dynamic building industry, where the competition for market share is intense, there is an enormous incentive to minimize the time for product development. This incentive sometimes means that the full ramifications of any new products, and particularity any limitations, are not always understood at the time they are introduced to the market.

Two examples illustrate the problem.

(i) When a zinc/aluminum coated metal cladding was first introduced to the Australian market in the late 1970s severe blackening of the material occurred on product. The alarming change in appearance of the sheeting, which was subsequently shown to have no detrimental influence on durability performance, occurred when moist conditions prevailed during storage. While the manufacturer was able to alter the system of surface passivation within a short time to markedly reduce the problem, the anxieties could have been avoided had the problem been identified prior to launching the product. More recently the product has been supplied with a very thin acrylic coating to further reduce the potential for wet storage staining.

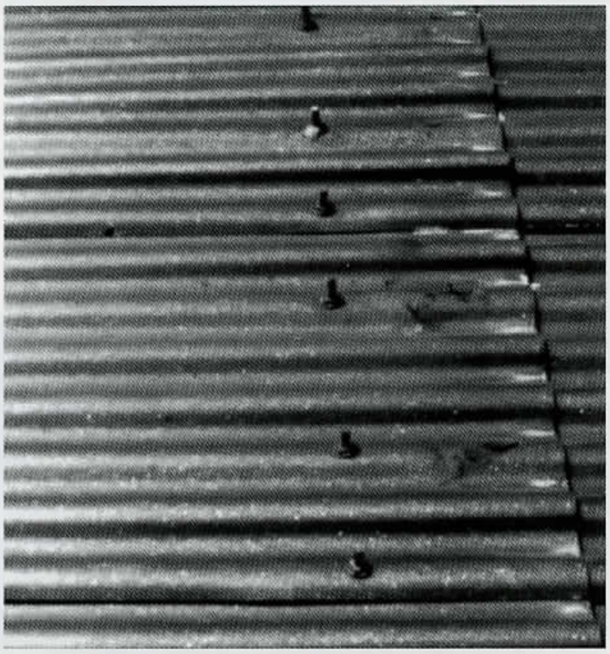
(ii) When fine cracking occurred in the coating on one of the first PVF_2 coated zinc/aluminum coated steel building facades in Australia, the matter was traced to a manufacturing problem. The final stage of manufacture of the coated metal included an embossing process in which the precoated cladding was slightly distorted. Investigations proved that the cracking of the organic coating occurred only on days when the ambient temperature of embossing was low and the coating was correspondingly less ductile. The problem was overcome by preheating the metal when the ambient temperature was low.

Given the large quantities of sheet metal and coil coatings being produced, the ramifications of any problems such as these can be enormous. In consequence, the processes for selecting coatings for sheet and coil are well developed and painstaking. Quality assurance of the coating supplied by paint manufacturer and quality control of its application are also usually very high.

It is also noteworthy that within any commercial range of products, colors and profiles are quite limited. While this is in part due to the cost benefits of a limited product range, it also allows for a better technical focus on that range. For example, the colour range is quite restricted and in the main formulated using inert inorganic colors of proven long term performance. Thus, the more subdued earthy shades predominate, with little scope for the bright, clean colors which, on balance, might be moe prone to chalk and fade.

DESIGN

Deficiencies in design are arguably the most common reason why coated steel claddings fail to achieve optimum performance. For most steel structures the cross-section of metal is usually much thicker than with sheet cladding, where there is little margin for error in designing the product for corrosive environments. Indeed for most sheet metal structures the coating will generally fail prematurely and the sheet perforate in small discrete areas, rendering the building obsolete long before most of the metal is seriously deteriorated. Notably, the steel tends to perforate first at laps in sheets, at flashings, in



Metal cladding is most vulnerable to corrosion at points where moisture can collect, such as between faying sheet surfaces.

rainwater goods, at fasteners or other point of vulnerability, where surfaces retain moisture or are subject to other influences such as dissimilar metal contact or mechanical damage.

Perhaps the most significant design problem with steel roofs over the last few decades has been the indiscriminate use of low pitches. Because low roof pitches encourage water to pond, particularly at the inevitable localized depressions and where sheets and flashing are in contact, the life can be severely reduced due to corrosion. The problem of corrosion is not confined to the top of roofs but is common within open structures, such as aircraft hangers, where condensation, particularly in the presence of coastal salts, can cause more rapid corrosion. For this reason regular washing of metal sheeting in areas protected from rain washing is a most useful maintenance activity.

The greatest points of vulnerability, in terms of corrosion, are the cut edge and the unpainted or lightly painted underside. The cut edge is vulnerable because of the difficulty of sealing this point in a manner which will provide corrosion protection as effective as for planar surfaces. This is not a problem for thinner coatings which are used in more benign environments where durability performance does not rely on sealing the cut edge.

Three factors limit the success of sealing the sharp edge:

- they thwart the build up of coatings as the paint tends to contract away from edges and corners.
- it is difficult or impractical to confirm by measurement the uniformity of the coating at sharp edges.
- edge sealing is not entirely a factory process and is in part carried out in the field where control is more difficult.

Poor flashing design can allow moisture access.

Metal flashings have been a particular design problem, not only because of the cut edge but, because of the potential for ingress of moisture to the rear of the sheet at this point which is usually poorly protected. Because of this problem there has been a trend to use more durable, coated aluminum for flashings and trim. The aluminum is inherently more durable than coated steel sheet and not reliant on a uniform coating over the cut edge to maintain integrity.

INSTALLATION

Three installation problems persist within the industry, swarf, trim or repair coats and fasteners.

(i) Swarf

Swarf, the steel debris produced from sawing or drilling metal roofing, and discards such as nails and rivet shanks, if left on roofs after installation will cause rust staining and accelerate sheet corrosion. It is a problem for both bare metal and painted roofs. The problem is very common and all the more disconcerting because it is well known within the industry and can be readily avoided by diligent clean up at the end of the job.

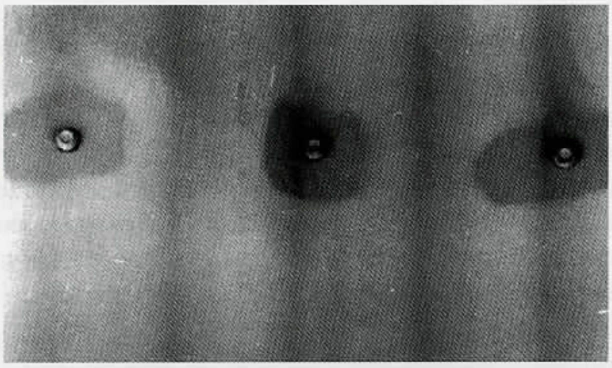
(ii) Trim and Repair Coats

There was a significant improvement in the chalking resistance of precoated metal cladding when the traditional vinyls were superseded with polyester and silicon modified polyesters in the early 1970s. Indeed the chalking resistance of contemporary precoated metal cladding is significantly better than conventional gloss alkyd enamel paints and more particularly than the pressure pack repair kits commonly used to reinstate damaged finishes.

This presents two problems:

- alkyd enamel paint finishes on metal and timber trim for example, which has been colour matched to adjacent areas of precoated metal cladding, will appear progressively lighter in colour with the passing years as it chalks at a more rapid rate than the factory finished coated metal cladding. This problem can be avoided by using contrasting colors where possible or using a more chalk resistant coating such as an acrylic latex paint on adjacent trim.

- when pressure pack repair coatings are used in an indiscriminate manner or over large discrete areas the contrasting performance of the repair and factory finishes can be most significant. It is therefore important that touching up damage with such paints is carried out with discretion.



Indiscriminate use of touch-up paints results in poor appearance after weathering.

It needs to be appreciated that the factory finish coat is essentially decorative and, on well drained exposed surfaces, defects in the coating have no great impact on service life. Rather, corrosion failures will invariably first occur in the inevitable areas of greatest wetness. Thus, there is no need to repair small scratches unless they damage the base metal coating. Where scratches are larger or fixings or other peripherals need to be colour matched to the cladding, the surrounding area needs to be masked to limit the repair area and its consequent visual impact as it weathers differently. Where damage has significantly impaired the integrity of the metal coating, sheets will probably need to be replaced.

(iii) Fastener Selection

Too often fasteners used to fix the sheets do not have the durability performance to match the roofing material. Particularly since the introduction of zinc/aluminum alloy coated sheet and improvements in the durability of factory applied organic coatings, the use of unpainted hot dip galvanized fixings, or worse thin electroplated fixings, are seen as increasingly unacceptable. For example, while hot dip galvanized fasteners (40 micrometer coating thickness) are standard practice for zinc/aluminum alloy coated steel (20 micrometer coating thickness) given that the latter is at least twofold the durability, rusting of fasteners can be expected before it occurs on the cladding in exterior service.

EXPECTING THE UNEXPECTED

Perhaps the most disillusioning types of cladding failures, and indeed materials failures in general, are those failures it might be argued that the problem could have been avoided if broadly based expertise had been brought to bear during product development and design. However, it is easy to be critical in hindsight, as the following two examples highlight.

(i) The introduction of zinc/aluminum alloy coated steel to the market with its enhanced corrosion resistance compared with the same thickness of galvanizing was reasonably seen as likely to improve the durability performance of the same product when overcoated. For conventional low build coatings this has indeed proven to be so. However for barrier coatings of significantly greater thickness, typically 80 micrometers or more, the coating has proved to be more vulnerable at the cut edge and other points of coating discontinuity.

This is believed to be due to the much slower rate of diffusion of oxygen through a thicker coatings. Thus, the corrosion crevice at the interface between the coating and the cut edge of the sheet will be more anodic than it would

Severe breakdown of PVC coating on horizontal surface, in contrast with sound condition of vertical sheets with cooler vertical orientation.

if oxygen diffusion to that point was greater.

(ii) Plasticized PVC laminated galvanized sheet has been a most successful cladding material with case histories in coastal and industrial service span more than 25 years.

Some 15 years ago a spate of dramatic failures of the material occurred in Australia, such that the coating disintegrated and rapid rusting of the base metal occurred within about 4 years. The problem only occurred with darker colored product, and on horizontal and near horizontal roofs where the underside was thermally insulated.

The failure was shown to be due to the high surface temperature reached with this combination of factors; the thermal decomposition of the PVC generated hydrochloric acid which attacked the metal substrate. Here was an example of a material, highly appropriate for one purpose, which failed catastrophically when some of the conditions were changed.

BRIGHT AND SHINY CLADDINGS

A review of the performance of decorative metal roof and wall claddings would be incomplete without some reference to metal claddings which are decorative without the need for an applied coating.

The lustrous appearance of corrosion resistant metals has always been an attraction for the building designer, as the great bronze clad Colossus of Rhodes, built in 280 BC, will attest. While metal cladding was used on buildings from the 1860's, it was not until the commercial development of stainless steels, prior to WW2 that interest in bright shiny metal facades was reawakened as a commercial possibility for building facades.

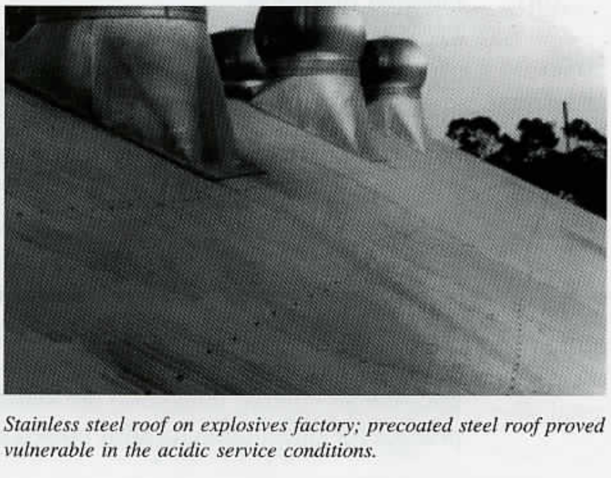
Stainless Steel

The durability of stainless steel is largely governed by the concentration of special alloying elements, notably chromium, nickel and molybdenum. Types 304 and 316 dominate the building market. Type 316 tends to be the preferred stainless steel for cladding in UK and Western Europe, probably because of its enhanced resistance to chlorides and moist sulfurous atmospheres. In North America the cheaper Type 304 is more common.

These stainless steels perform well in most conditions of atmospheric service, as demonstrated by the Chrysler building, built in New York in the 1930's. This building has the roof sheathing and large ornamental gargoyles constructed from Type 302 stainless steel, a grade more susceptible to general and pitting corrosion than contemporary types used for cladding. It is apparently still in good condition after 60 years service.

Stainless steels are however not immune to corrosion or staining. Passivity for example can be impaired when small particles of carbon steel, copper scale or other foreign matter from the environment deposits on the stainless steel surface. They can be vulnerable to chlorides and in coastal locations, particularly in hotter areas, attack both by pitting and stress corrosion, can be severe. For example, lighthouses in temperate regions around Australia have performed well but some in tropical service have suffered both crevice and stress corrosion.

In terms of dirt retention stainless steel is no less susceptible than any other comparable inert, smooth surface. However, because any blemish to a highly reflective surface is readily noticed, and as the public perception of stainless steel is one of cleanliness and high reflectivity, there is an inherent aesthetic problem with stainless steel facades. Namely, they are usually required to be maintained, perhaps unreasonably, at a standard of cleanliness much higher than that demanded of the more traditional surfaces such as concrete and masonry. In short, stainless steel facades in coastal, industrial or in urban areas need to be cleaned regularly, typically at least every 12 months. They can be cleaned with water and a plastic scourer pad or belt device with polishing only in the direction of the original factory finish. Where stains are obstinate a chloride free, powered abrasive cleaner may be required. Under eaves and similar unwashed areas may need more frequent attention. In many industrial situations they are unsurpassed because of their high chemical resistance.



Stainless steel roof on explosives factory; precoated steel roof proved vulnerable in the acidic service conditions.

Aluminum

Aluminum has been in commercial production for less than 100 years and became a popular facing for buildings through the 1950's and 60's, with anodized aluminum largely displacing it after this time in exterior situations.

While the corrosion rate of aluminum is low in most conditions of atmospheric service, it slowly suffers pitting corrosion in industrialized situations to a depth of perhaps 200 micrometers in 40 years, in areas remote from the coastal fringe. This pitting generates disproportionately more voluminous corrosion products which, accompanied by dirt and grime, detract from the aesthetics, particularly in areas not exposed to cleansing rainwater. Thus while bare aluminum can be regarded as extremely durable, the appearance of unwashed surfaces suffers considerably after a few decades. Aluminum claddings are lighter than coated steel but have lower tensile strengths, with consequent limitations. They also have higher coefficients of thermal expansion which needs to be accommodated in the design, while most acids, strong alkalis and copper and copper salts are damaging.

Alloys that have commonly been used are 3004 (Al-2% Mn-1% Mg), Alcad 3004, with a layer of 7072 (an Al-1% Zn alloy, metallurgically bonded to it, which galvanically protects the core) and 5251 (Al-2% Mg).

Anodization of aluminum provides enhanced durability performance, depending upon the thickness of anodizing. For example, the intensity of pitting in aluminum with 22 micrometer of anodizing after some 8 years industrial atmospheric exposure was only one tenth that for the same material with only 12 micrometers of anodizing[10]. Anodized aluminum does however deteriorate outdoors, such that it is slowly eroded by wind borne particles, rain and chemical pollutants, and corrosion products accumulate on the surface to mar the appearance.

In order to maintain the appearance of anodized aluminum it is therefore necessary to maintain a regular cleaning regime, particularly because the corrosion products tend to consolidate with time and are more difficult to remove if cleaning is infrequent. Thus, even with a minimum anodizing thickness of 20 micrometers for sulfuric anodizing, and some 20% less for integral anodizing, a regular cleaning regime, typically six monthly, is necessary, particularly for exterior areas unwashed by rainfall.

Another aesthetic problem peculiar to colored anodized aluminum is the inevitable variation in colour from panel to panel. This variation is not only related to anodizing thickness but is an inherent characteristic of the product. It can result in great disagreement between builder and owner if colour variation is not properly addressed prior to fabrication. In short, the specifier needs to recognize the colour limitations of the product. It is advisable to have sample panels prepared prior to commencing the project. These sample panels must be selected to represent the upper and lower limits of colour intensity that will be tolerated. Further, agreement needs to be reached that this colour range can be reasonably achieved by the anodizing process. On site there may be a further opportunity to minimize the impact of colour variations by avoiding placing panels of marked colour difference close together. In recent years, it has become increasingly popular to use prepainted aluminum claddings, notably PVF_2, which avoids the variations in colour inevitable with colored anodized finishes.

CONCLUSIONS

This paper has highlighted that, notwithstanding the great successes of metal roof and wall cladding, a range of limitations and problems can and have been experienced with these products.

Some of these problems have been attributable to inappropriate product selection or building design, or indifferent handling, storage or installation. Other in-service problems have been due to either inherent limitations in the products, which are either not easily recognized by designers or installers or were problems not even perceived at the time the products were first marketed. They provide a salutary lesson to anyone marketing to the building industry, where competition encourages the fast tracking of new products.

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Editor.

CONTENTS

Cover:
*The first major SUPER*COR installation in Australia at the Nabalco Bauxite Mine, Nhulunbuy in the Northern Territory, manufactured by Ingal Civil Products. Read more about this innovative bridging system on page 21.*

CORROSION MANAGEMENT

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IN THIS ISSUE

- Durability branding system
- Performance of coated metal roof & wall claddings
- Avoiding embrittlement problems in chain
- Dew Point - relative humidity and air temperature
- Super*Cor - an innovative bridging system
- Hot dip galvanized protection in hydroponics