Paint failures —

An examination with use of a simple dynamic model

(First in a three-part series)

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IN MANY WAYS, paint films are like people; they are organic, made up of high polymeric materials, and are subject to a surprisingly similar process of degeneration. They do not last forever, but like us are heir to a million and one possible terminations. They have a finite service life, and the most that can be done is to see that they last for as long as possible.

Like all soldiers, the best of them never die catastrophically, they simply fade away by gradual erosion as oxygen, moisture, and sunlight combine to slowly break down the film and wear it away. In this manner, they may last 10, 20, even 50 years, but eventually they will powder away to nothing.

If a paint film lasts 20 or even 10 years, it must be considered successful. The term "failure" is more appropriately reserved for paint jobs that undergo catastrophic premature deterioration within the first one or two years of life. It is these failures that are considered here.

There are many causes of early paint film failure and a concise treatment of the subject is all but futile. Many common

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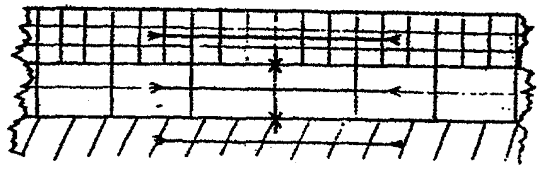


Figure 1

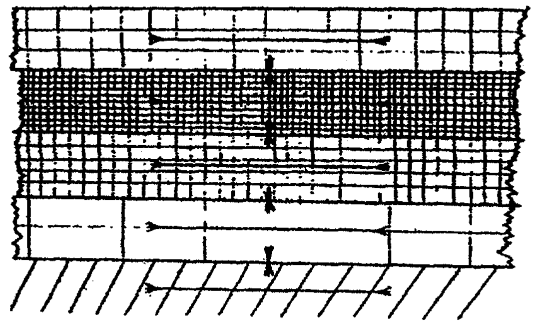


Figure 2

failures are, however, related, and can be understood by the use of a simple model, and by examining the way it responds to stresses in paint application and from the environment. By use of the model a variety of apparently unrelated paint failures will be discussed and they will be shown to be individual manifestations of similar fundamental problems.

The paint film model consists of: a substrate, a primer, and a top coat, held together by a series of connected forces. (**Figure 1**). In more complex systems where other intermediate coats are present, the composite may have a number of alternating interfaces and paint film continual held together by a series of adhesive and cohesive forces in equilibrium. (**Figure 2.**)

The substrate, of course, varies. Each substrate has its own peculiarities, which impact upon the design and effectiveness of the applied coating system. Cementitious substrates, for example, are often alkaline; metal surfaces tend to corrode; plastic surfaces may be subject to attack from the solvent carriers of the coating system; and wood, being highly heterogeneous, is subject to dimensional changes as alternating bands of summerwood and springwood respond to climatic conditions.

First to be considered is how elements of composite paint systems interact. Failures can be related to mismatched strengths of elements of a paint system and their adhesion to each other.

Under ideal conditons where no external stresses are applied to a system and where age-related phenomena do not take place, the composite will maintain its equilibrium indefinitely, regardless of the quality of the adhesive and cohesive forces that hold the system together.

In the real world, however, neither substrate nor paint film are static entities, and when the system is put into service it must exist in the stress-producing environment. The elements of the substrate/paint system composite are dynamic entities, which, inevitably, respond to hot/cold and humid/dry cycling as well as actual mechanical movements such as caused by impact, vibration, or bending. Certain substrates, such as wood, do not respond uniformly to such

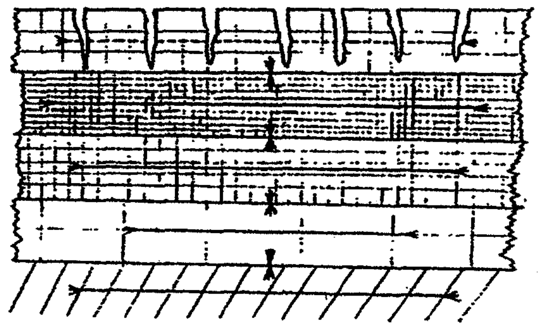


Figure 3

stresses, and its heterogeneity is what makes wood so difficult a substrate to paint.

In fact, no substrate nor paint film will respond in quite the same degree as another to such environmental stresses and this differential is often instrumental in paint failure.

The substrate continuum of the mold is held together by lateral cohesive forces. The primer is anchored to the substrate by vertical adhesive forces and is itself held together by cohesive strength. Similarly, the continua of all films above the primer are held together by their own lateral cohesive forces and are affixed to the coatings beneath them by vertical forces, which may or may not be different from the force that anchors the primer to the substrate.

As long as each composite layer adheres to those layers that sandwich it and as long as each layer retains sufficient cohesive strength to maintain its own integrity, responses in any one component to stress will cause a response in other components, producing a complex series of strainings throughout the system in each individual component and across each interface. As long as such straining forces do not exceed the cohesive strengths of continua or the adhesive strengths across any interface, equilibrium will be maintained and the paint system composite will successfully work.

Paint system failures occur when the cohesion of any element of the system or the adhesion of any element to another is insufficiently strong to withstand the demands that the total composite exacts upon the individual film, as the system responds to the service environmental demands.

Let us examine a situation, for example, where the applied film has acceptable adhesion between all coats, but the finish coat is more brittle and less strong than the underlying coats. Unless the brittleness of the topcoat is overly marked, application will produce little problem and the total composite will behave well until it responds to a significant stress.

For example, if there is a prefinished board that is coated indoors and it is put outside to respond to a typical summer/winter cycle, the board will expand in hot conditions and contract in cold or dry conditions. These changes will not take place once, but will be repeated.

Their effect on the coating depends on the viscoelastic properties and the coefficient of expansion of the elements of the total composite. Continual climatic cycling produces a considerable flexing of the system. Under such conditions, the cohesion of the topcoat is progressively weakened until failure occurs as the built-up strains in the topcoat are dissipated by cracking. (**Figure 3**).

If the topcoat film is very weak, such as

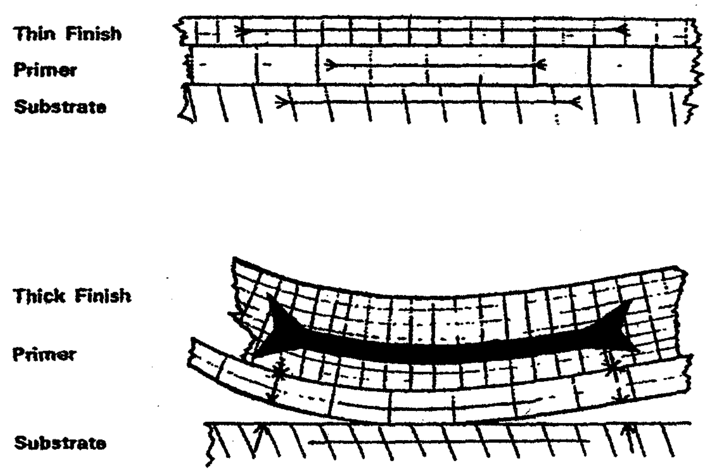


Figure 4

might be found in a poor underbound film (rare in exterior systems), the strains will dissipate as a fine mud-cracking, which may not be visible. In most exterior systems, having better general cohesion, the cracking will be more macro in nature, and thus result in a severe checking or cracking failure visible in the top-coat.

Oil paints are oxidizing systems that begin life as flexible systems, but, as they age, progressively undergo chemical changes such as autoxidation, excessive crosslinking, and chain schism. In practical terms the film gradually becomes more and more brittle.

Thus, films, which once could withstand a great deal of flexing, inevitably, become just too brittle to withstand such flexing, and the resultant strains may be dissipated in deep cracks. Films lower in the composite are older, and therefore, generally more brittle than the upper films. If adhesion is good across all coating/coating inerfaces, cracks in one coat will often result in cracks in lower films, and vice versa.

The strength of a cohesive paint system will, of course, increase with the film thickness of the system. (**Figure 4**). As the cohesive strength increases, the greater will be the corresponding demand that the system exerts on its adhesive forces, which anchor it to lower film or substrate. Unfortunately, the adhesion of a system is finite. Measurements can be taken to artificially improve adhesion, but once dried, paints will never increase their adhesion. If the cohesion becomes too strong, under service induced stresses, the adhesion may not be able to cope with the demands of the coating system.

The stonger cohesive forces will in this way literally pull the underlying film from the substrate and the system will peel.

Such adhesive failures need not necessarily take place across the interface between the strong film and the film directly below it. If the adhesion across this interface is good, and better than the adhesion across a second lower interface, the resulting failure will occur further down the composite at the lower interface, and the lower film will be stripped from its substrate or film to which it adheres. ((**Figure 5**).

On the other hand, if the continuum of the lower film is weaker than the adhesion across both interfaces, the strain in the system may be dissipated by the cohesive failure in the lower film. In this case, fragments of the lower film will be seen on the

Figure 5

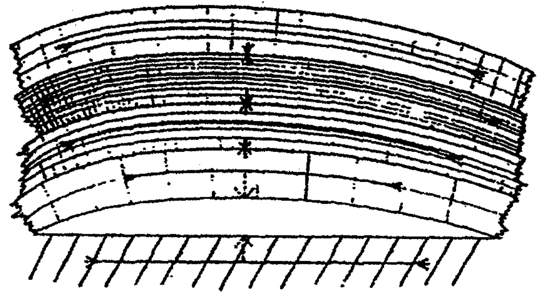
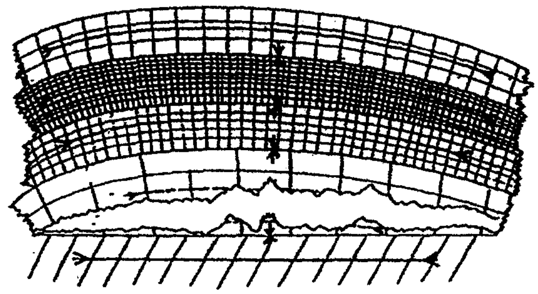


Figure 6



underside of the composite film delaminating and on the surface bared by the delamination. (**Figure 6**). It is important to realize that under stress, a coating system will always fail at its weakest point, whether this be at a poorly prepared interface, or in the continuum of a poorly cohesive film.

The two foregoing failure models are well illustrated by practical paint film failures.

Our illustration of adhesive failure at lower, less secure interfaces caused by strain produced by a strong or flexible topcoat is the cause of what has become one of the most common types of exterior paint failures in the Northeast. In this part of the country, there are many older homes that have for years been painted with oil paints. These oxidizing systems over a period suffer from the embrittling processes described above.

As these aging processes occur, the coating film responds progressively less easily to climatic differentials. In the late 1950s and early 1960s, with the introduction of latex house paints, there was a fashion among home owners to abandon the old solvent-thinned oil paints for the convenience of the water-reducible latex finishes.

Unfortunately, the latex finishes are thermoplastic materials (unlike oil paints, which are thermosetting systems), and respond greatly to differentials in temperature and humidity. The latex film is as flexible as the old oil film is brittle. As the adhesion of the latex film to the old oil paint is, under normal circumstances, very good, the marked expansion and contraction of the latex film puts the system under very significant stress. Generally, the oil film is cohesively very strong, and so this stress is all too often felt most keenly at the interface of the first coat of oil paint and the wooden substrate.

Caught between these two stresses, the old oil paint is literally stripped from the wood by the latex film (bringing with it all intermediate oil films that had been applied in the interval between the last painting and the original painting) and the house is bared of paint to the original wooden substrate.

The phenomena becomes worse as the cohesion of the latex film increases. Thus, the thicker the latex paint or the greater the number of latex coats, or the higher its gloss (the lower its pigment volume concentration), the greater is the stress that is exerted on the total system. Similarly, the older and more brittle the oil paint, or, for any other reason, the lower the security of its adhesion to the wood, the more that paint system will be subject to this type of failure.

The cardinal rule of house painting, particularly on old houses, is to apply oil paint over oil paint and latex paint over latex paint. Never apply a latex paint (especially a high-gloss latex paint) to the siding of a house that bears an old oil paint system next to the wood. This is particularly true if the old oil paint system shows signs, before painting, of weakened adhesion at the original wood interface.

Equally commonplace is the illustration of strong topcoats producing cohesive failure in poorly bound paint films that lie lower (nearer the substrate) in the total paint composite. In this case, the failure is typically found on ceilings in old houses, apartments, schools and other institutional buildings. For years, the practice was for ceiling paints to be formulated from limed oils, calcicoater vehicles or simple calcimine and distempers. All these materials were cheap, opaque, but quite underbound.

In many cases, there was little real vehicle present, and the film could be readily removed by washing with soapy water. Few folks had cause to wash ceilings, however, and for years these paints produced good service, as ceilings were continuously recoated with similar products as needs arose. With the advent of the better-bound ceiling paints, such as flat alkyds and latex flats, the situation became more complicated. These paints, while in their own right of better quality than the calcicoater materials, were inappropriate for use on this type of ceiling.

Being more cohesive and much stronger than the poorly bound ceiling paints to which they were applied, these paints induced considerable stress into the system. As film thicknesses built up, the strength of the upper layers of the composite greatly increased in comparison to the strength of the lower layers of the composite to the point that as the system was put under stress, the composite failed within the continuum of the underbound calcicoater films deeply embedded within the total composite. Stress was often derived from the differences in humidity and temperature during the summer and winter.

More often than not in such situations, however, failure is more likely to occur at, or just after the application of an additional coat of paint, than in the long run as a result of climatic differentials. As new coatings are applied, the water or solvents that carry the new paint tend to penetrate into the older films and produce considerable expansion. This expansion is followed by significant contraction as the water or solvents evaporate from the system and the system dries out.

These two marked changes produce even greater stresses than normal environmental stresses, sufficient to cause significant delamination. This particular failure had caused many headaches in the renovation of older structures, where the interior paint systems have been subject to rather more extreme conditions of cold and humidity that occur when buildings are left open during partial renovation and closed just before painting. As the heat is restored, or after new paint application, significant failure of the existing composite occurs, with large amounts of ceiling areas peeling and requiring complete refinishing.