

CHEMICAL STRIPPERS AND SURFACE-TOLERANT COATINGS: A TANDEM APPROACH FOR STEEL AND CONCRETE

By Mike O'Donoghue, Ph.D., Ron Garrett, Ron Graham, and V.J. Datta, M.Sc., ICI Devco Coatings; Sergio Vitomir, M.A.Sc., and D. White, Napier International Technologies Inc.; and Leslie Peer, Ph.D., P.Eng., Read Jones Christoffersen Ltd.

In recent years, with increasing environmental and economic constraints, a diverse range of alternatives to abrasive blasting has emerged. With this shift from traditional methods of surface preparation, the use of chemical strippers is gaining acceptance in industrial and marine applications. There are several reasons for the growing use of chemical stripping, all related to the impediments to traditional abrasive blasting. For instance, abrasive blasting near complex machinery warrants extreme precautions and is generally prohibited because errant abrasive can damage critical components of the process equipment. Abrasive blasting may also be a source of ignition in explosion-sensitive sites. Furthermore, there is always a risk to trades nearby. Work may be shut down to protect personnel from airborne contaminants. Moreover, the requirement for efficient containment systems and disposal of abrasive and paint debris can make abrasive blasting prohibitively expensive. Hence, where abrasive blasting is prohibited, impractical, or impossible, it can be replaced with safe, effective chemical strippers.

With this shift from traditional methods of surface preparation comes

RESEARCH

an increased use in coatings that can perform well over surfaces that have not been prepared to a high level of cleanliness. Written in light of these two trends, this article focuses on

*Here's
research on
the feasibility
of one
alternative to
abrasive
blasting and
recoating in
sensitive areas.*

chemical stripping research with surface-tolerant penetrant sealers for coating and recoating rusted steel as well as mature and green concrete.

First, the article discusses three

generic types of chemical strippers: two that have been classified by convention as bond breakers and caustics; and a third, new generic type designated as selective adhesion release agents (SARA). Second, the article describes performance testing of three versions of SARA technology on coated steel and concrete.

Third, the article turns to the issue of surface-tolerant coatings over chemically cleaned steel. It reports on the performance of a variety of penetrant sealers on previously coated steel that had been cleaned by SARA technology. Data on the penetrant and adhesion characteristics of coatings before stripping and recoating are drawn from research reported in an earlier article.¹

CHEMICAL STRIPPERS: GENERIC TYPES AND APPLICATION PROCEDURES

Paint and coating strippers must contend with complex and multiple adhesion forces between the material to be removed from the underlying substrate, as well as cohesive forces in the material itself.

According to ASTM D 907, adhesion is defined as "the state in which two surfaces are held together by interfacial forces which may consist of valence forces or interlocking action or both."² While no one theory fully accounts for adhesion, in more technical terms, adhesive forces are considered the sum of all chemical and physical interatomic or intermolecular interactions, and it is these interactions that

Editor's Note: This article was condensed from a paper presented at PCE 2000 in Genoa, Italy, March 8-10, 2000, and published in the conference proceedings, Assessing the Future of Coating Work. For the full test results and discussion, readers are referred to the proceedings paper. The proceedings is available from the PCE conference sponsor, Protective Coatings Europe, +1/412/431-8300; +1/412/431-5428; web site: www.protectivecoatings.com.

must be speedily and effectively overcome in chemical stripping.

Before 1996, there were essentially two categories of chemical strippers described in the literature: bond breakers and caustics.³ Since 1996, a new classification of chemical stripper has arisen described as SARAs. A brief overview is given below for all three stripper types, along with suggestions for reclassifying bond breakers and caustics.

Bond Breakers

Chemical strippers designated as bond breakers are often based on, and typified by, low molecular weight hydrocarbon solvents such as methylene chloride, xylene, and toluene, or low molecular weight oxygenated solvents like acetone, methanol, and methyl ethyl ketone. These compounds are toxic and flammable, regulated for volatile organic compounds (VOCs), and have unpleasant odors. Thus, they require many protective measures for workers and others in the vicinity of their use.

To the organic chemist, bond breaking infers chemical dissociation, hydrolysis, solvolysis, and a myriad of other chemical reactions that break primary valence bonds. However, the mechanism of materials currently described as bond breakers is not a chemical reaction. Instead, these materials penetrate into the free volume of the coating film, swell the film, and lift it from the substrate. These strippers induce severe compressive stresses and subsequent mechanical failure of the film.

How fast the stripping action takes place is a function of the rate of stripper diffusion into the polymeric structure of the coating film and the solubility of the stripper once inside, assuming that sufficient stripper is present. Overall, the diffusion process is complex and depends in large part on the size, polarity, and shape of the stripper molecules. Solvents characterized by high polarity

Continued

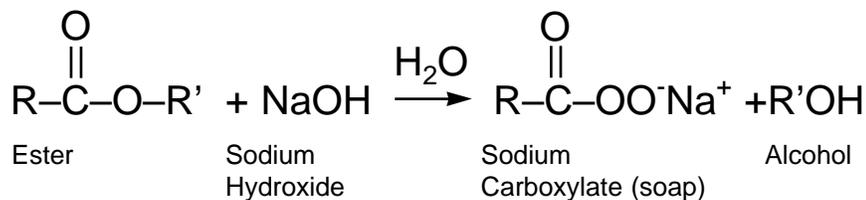


Fig. 1: Caustic stripper: base-promoted hydrolysis of an ester group in an alkyd paint (saponification)

and low molecular weight prove to be more aggressive. Also, the diffusion process is a function of the spatial configuration, crosslink density, free volume, molecular motion, and glass transition temperature (T_g) of the coating.

A comprehensive treatment of free volume concepts and the effects of solvents on coating films has been given by Hare⁴ and is beyond the scope of this article. Ultimately, however, the stripping action with methylene chloride-based and similar strippers is far more of a physical process than the scission of chemical bonds. Since this technology deals with physico-chemical secondary valence bonds and physical adhesion, chemical strippers presently categorized as bond breakers are thus more appropriately classified as “stress-inducing release agents.”

Methylene Chloride-Type Strippers

The earliest and still most commonly used chemical strippers are formula-

tions based on methylene chloride, such as methylene chloride/methanol blends or methylene chloride/phenol blends. To put things in perspective, by 1990, methylene chloride was still the principal chemical ingredient in over 90% of the paint strippers.

Methylene chloride-based strippers are sometimes augmented by either acidic or alkaline compounds to improve their stripping action. For example, the lower carboxylic acid—formic acid—is often used because of its high reactivity as well as its powerful solvent characteristics.

While it cannot be denied that methylene chloride-based products have been very effective as general stripping agents in residential, commercial, and industrial settings, they do have limitations. First, they tend to dry out fairly quickly because of their high volatility; therefore, multiple applications are necessary to remove thick films. Second, in the event of

drying out, the hardened residual mass can be more difficult to remove than the original coating itself. Third, these strippers tend to lift only a few coats at any given time, say one to four coats of an alkyd paint.

It is also important to note that methylene chloride is highly toxic to humans and hazardous to the environment. Because methylene chloride is a recognized carcinogen and potential ozone depleting agent, some governments have restricted or banned its use or are considering doing so. The U.S. Occupational Safety and Health Administration (OSHA) has determined that even very low exposures create a significant health risk to employees.

N-methylpyrrolidone- and Dibasic Ester-Based Strippers

Within the last decade, chemical strippers have become more elegant, less toxic, and less detrimental to the environment. Formulators have blended non-flammable and non-combustible solvents such as N-methylpyrrolidone (NMP) and dibasic esters (DBE). This type of so-called bond breaker formulation can easily remove multiple coats of alkyds (e.g., 10 layers in 24 hours), latexes, and lacquers. Some of these strippers have reasonable success in removing lower end formulations of two-component epoxies and urethanes.

Like methylene chloride-based strippers, chemical strippers based on NMP/DBE blends essentially function by penetrating coating films and progressively diffusing to the coating-substrate interface while exerting compressive forces in the film. The lower volatility of such strippers aids solvent retention in the film and enables the film to remain wet for prolonged periods of time. They are also biodegradable and lower in VOCs than methylene chloride-type strippers.

When formulated with select materials to insolubilize lead, NMP/DBE-based strippers can remove lead-

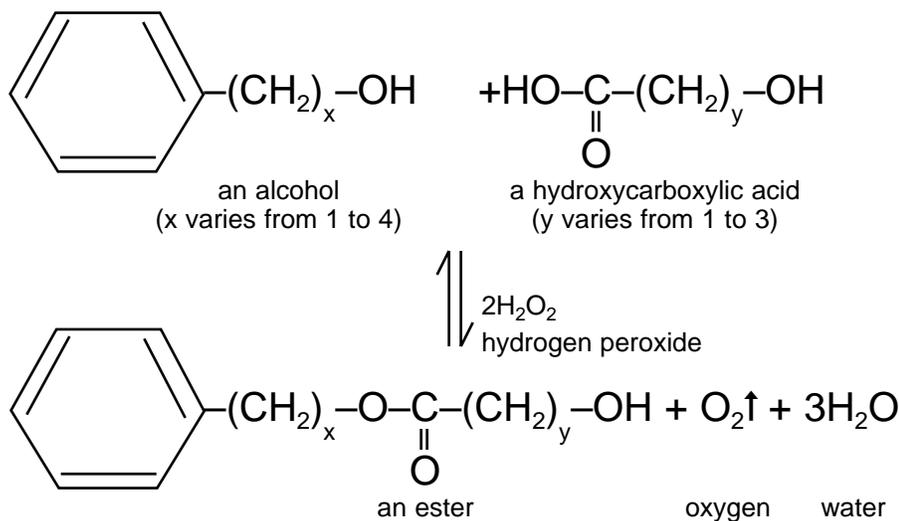


Fig. 2: An alcohol hydroxycarboxylic acid peroxide (AHP) stripping system, designated as a selective adhesion release agent (SARA)

based alkyd paints from bridges, thereby minimizing airborne particulates (lead dust exposure < OSHA's PEL of 50 $\mu\text{g}/\text{m}^3$ or the action level of 30 $\mu\text{g}/\text{m}^3$). A moist waste is produced that is suitable for easy disposal.

These strippers have their own drawbacks. When applied to an epoxy or polyurethane coated substrate, they would strip the old coatings as quickly as methylene chloride-based products. However, this is generally not the case. NMP and DBE are weak solvents. In most instances, the more chemical-resistant coating films are still a substantial challenge for NMP/DBE-based strippers. Further chemical design improvements are needed in their formulations to effectively remove such films.

Caustic-Based Strippers

Caustic strippers have recently been documented as the second of two

generic types of paint remover.³ They are based on alkaline compounds such as sodium, calcium, potassium, and magnesium hydroxide. Generally recognized to have less versatility than solvent-based bond breakers, caustic strippers work through alkali-induced hydrolysis of ester groups. Therefore, they are useful for removal of epoxy esters, saturated polyesters, and multi-layered alkyd systems, even when the latter have DFTs up to 500 μm (20 mils). In contrast, because epoxy coatings lack ester linkages, they are quite resistant to attack by caustic strippers. Thus, caustics have a narrower range of effectiveness on different types of paints and coatings. For example, they do not work on latexes and epoxies; they will react with paints containing aluminum (because of the amphoteric nature of aluminum), causing hydrogen to be liberated.

Ironically, the mechanism of coating

removal for caustics is more representative of true chemical bond breaking than the mechanism of so-called bond breakers. Figure 1 shows the chemical degradation of an alkyd paint by saponification, a process that involves actual cleaving or breaking primary valence bonds. Amide bonds are also very susceptible to hydrolytic attack from caustic strippers.

Originally developed for paint dipping processes, caustics have been used recently with ice blasting for lead paint removal on bridges.⁵ Under the conditions reported, a spray-applied caustic stripper successfully dissolved lead paint in approximately four hours. The subsequent use of ice blasting was effective for rinsing, neutralization, and waste minimization.

Much thicker films of caustics must be applied (compared to so-called bond breakers) to achieve efficient

Continued

paint removal from the underlying surface. Thicker films of caustics can mean more waste. Stripped surfaces must be neutralized before new coatings are applied. Contractors working with caustic strippers must exercise great caution because caustics can burn skin and eyes.

Selective Adhesion Release Agents— A New Generic Classification

Invented and patented in the mid-90s, the selective adhesion release agents (SARA) are based on alcohol hydroxycarboxylic acid peroxide (AHP) systems (Fig. 2). They represent a third, and heretofore unclassified, generic type of coating stripper.⁶

SARA stripper formulations are water-borne macro-emulsions that consist of a non-polar phase emulsified into a polar phase. The non-polar phase is a blend of solvents that are neither soluble nor miscible in water. The polar phase is predominantly deionized water; it also contains other polar molecules. All the constituents of the stripper are 100% biodegradable in water and soil, and are essentially not harmful to workers handling them. Gloves or goggles are not normally recommended or required for working with SARAs.

Compared to the highly toxic chemical strippers, SARAs were engineered to utilize less toxic and less powerful chemicals with other materials that have high physical activity. This combination compensates for the use of otherwise deleterious chemicals while achieving equal or better stripping power.

SARA strippers have several practical features. They can remove multiple layers of single-component paints such as alkyds, latexes, epoxy esters, oil-modified urethanes, or moisture-cured urethanes.

They can also efficiently strip a broad spectrum of water-borne, solvented, or solventless two-component cured systems, including amine and polyamide epoxies and acrylic or poly-

ester polyurethanes. Odorless, or possessing a mild and pleasant odor, they work quickly and efficiently inside or outside a facility with practically no waste to deal with. Removed coatings are then disposed of in accordance with all applicable regulations.

They come in brush, dipping, and spray grades; the latter hang well to

vertical and overhead surfaces.

A disadvantage of SARAs is that in some cases, compared to other types of strippers, the removal time may be somewhat longer.

And, like the bond breakers and caustics, SARAs either fail, or work poorly, with many of the highly

Continued

crosslinked thermosets like novolac epoxies and vinyl esters. Steric hindrance and shielding of reactive groups, high T_g s, and low free volumes all contribute to the excellent chemical resistance of such coatings to attack by chemical strippers. Thus, as with the bond breakers and caustics, there is room for improvement in the SARA technology.

A three-phase chemical stripping mechanism of SARAs has recently been elucidated.⁷ (See sidebar below.)

Application of Chemical Strippers

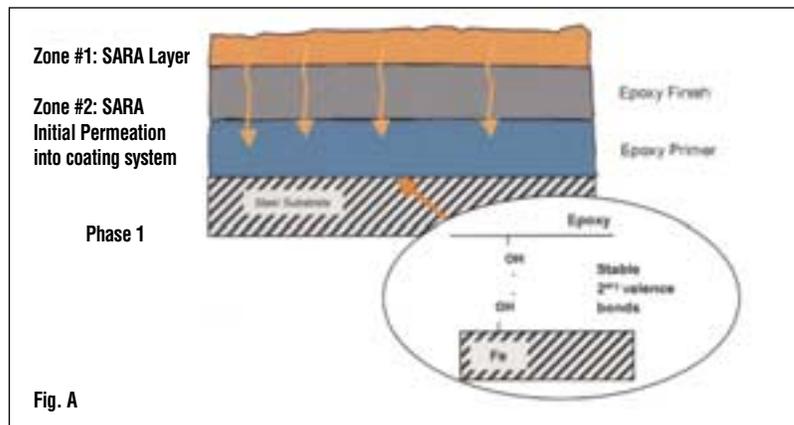
Regardless of the generic type of chemical stripper, there are usually four steps to consider with any coating removal project: application, dwell time, removal, and refinishing. As with other methods of surface preparation, factors such as accessibility, environmental conditions, and disposal must be taken into account.

When multiple coating layers or very thick anti-corrosive

THE CHEMICAL STRIPPING MECHANISM OF SELECTIVE ADHESION RELEASE AGENTS

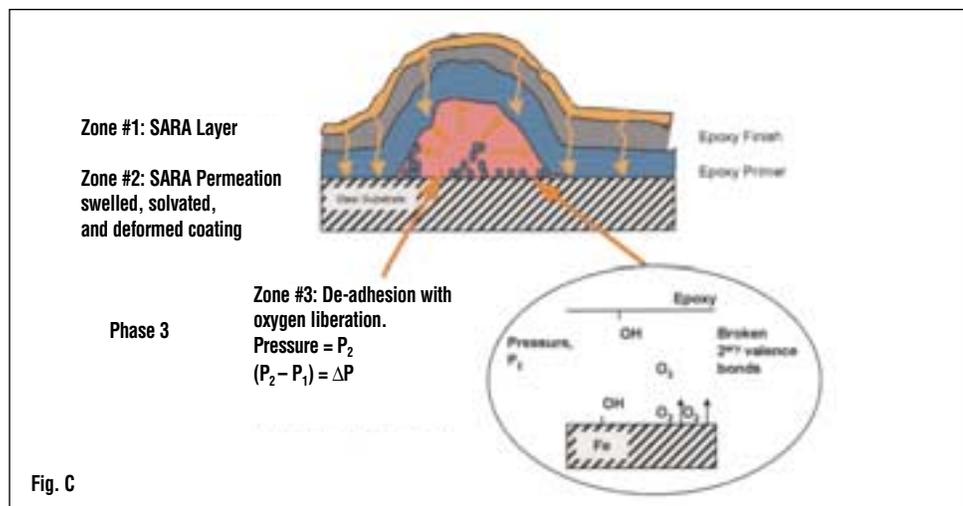
A three-phase stripping mechanism of SARA technology is proposed as follows.

- Phase 1 (Fig. A): The stripper diffuses and penetrates free volume holes in the coating, progressively moving towards the underlying substrate and inducing stress and physical changes in the coating. Simultaneously, a paraffinic phase migrates to, and stabilizes at, the external surface of the stripper. This process increases the residence time of the low volatile stripper inside the coating. These processes are intrinsically similar to the penetrant diffusion, penetrant solubility, and wax precipitation mode of action of methylene chloride and NMP/DBE based strippers as described by Hare.⁴
- Phase 2 (Fig. B): The stripper has virtually permeated through the entire coating and has closely approached the coating-substrate interface. With the bonds to the substrate dramatically destabilized from swelling and deformation in the compressively stressed coating system, a developing negative pressure, P_1 , is created at the interface between the (primer) coating and the substrate. This is a significant discovery in the context of the stripping mechanism that follows. Specific ingredients in the SARA formulation will selectively recognize the substrate and use that substrate as a catalyst to speed up the stripping process. Phases 1 and 2 make up the stripper diffusion-coating stress step.
- Phase 3 (Fig. C): The SARA stripper has completely permeated through the coating and contacted



Figures courtesy of the authors

the substrate, whereupon immediate and abundant gas formation is initiated at the coating-substrate interface due to the decomposition of a select compound (such as hydrogen peroxide) in the stripper. Initially formed nascent oxygen combines to form molecular oxygen. The release of oxygen results in a positive pressure, P_2 . Hence, a negative-to-positive pressure inversion occurs due to the $P_2 > P_1$



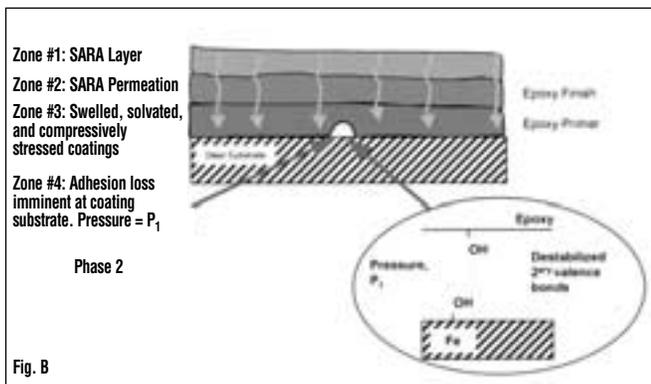
coatings require removal, it is recommended that a test patch of chemical stripper be applied on the existing coating. The patch test establishes the so-called "dwell time" or amount of time needed for it to lift that coating. Dwell times will vary depending on the type of material, the number of coating layers on the substrate, ambient and substrate temperatures, and the generic type of stripper employed. While monitoring ambient conditions, scrape the paint or coating

system at different time intervals to determine if the coating is softened enough to be removed. This stage defines the dwell time.

Manufacturers' data sheets should be followed closely. Most chemical strippers based on NMP/DBE bond breaker technology, caustic technology, or SARA technology can be applied by brush, roller, or airless spray. Caustics can also be applied by air spray. Effective paint or coating removal typically occurs within one to six hours. However, it is often recommended that the stripper be left overnight on existing paint systems to fully utilize non-productive time. The coatings are easily removed the next morning, usually without a second application of stripper. When multiple layers are removed, there may be poor adhesion between them. In these cases, the stripper may lift coating layers before reaching the substrate. If so, the lifted layers are removed and more stripper must be applied. Should the stripper dry before all paint layers are lifted, reapplication of the stripper will be necessary.

It is suggested that most strippers be applied away from direct sunlight to prevent premature drying. Premature drying can also be avoided by placing a polyethylene sheet over the wetted surface. In the case of some coatings re-

Continued



(ΔP) pressure differential. The sudden pressure transition/equilibrium beneath the stressed coating has been known to produce a popping sound in some instances. Also, the pressure inversion causes the onset of lateral and vertical coating detachment from the substrate. This is the stripping or de-adhesion initiation step. The shearing forces experienced by the stressed coating and the further supply of gas spread the stripping action. Vulnerable adhesion sites between the coating and the substrate are disrupted. This is the stripping or de-adhesion propagation step. The stripping or de-adhesion termination step occurs when susceptible (primer) coating bonds are fully broken (some may remain unbroken) at the substrate and compressive stresses in the coating are relaxed.

During release, the coating film can lift, pucker, twist, shrivel, crumble, remain apparently flat, or assume any number of distorted shapes. The dimensional changes and configuration adopted will depend upon the particular stripper used and the chemical composition and T_g of the coating. Interestingly, methylene chloride-based strippers induce compressive stresses into the coating as described earlier. The authors contend that the above mentioned pressure transition scenario also occurs in methylene chloride-based strippers, where, as soon as the swollen coating cracks open, an entrance site is obtained for air to be sucked into the coating-substrate interfacial region.

Table 1:
Chemical Stripping: Time (hrs) To Remove Coatings (21 C [70 F])
from Abrasive Blasted Steel Using a SARA-1 Chemical Stripper

Coating Type	No. of Coats	Total DFT µm (mils)	Stripping Time (hrs)
Latexes			
Acrylic latex (i)	1	76 (3)	1
Elastomer acrylic latex	2	559 (22)	1
Acrylic latex (ii)	1	76 (3)	1
Alkyds			
Medium oil alkyd	2	64 (2)	1
Short oil alkyd	2	64 (2)	1
Silicone alkyd	2	76 (3)	1
Alkyd (multi-coats)	10	406 (16)	18
Organic Zinc			
	1	76 (3)	6
Calcium Sulfonate Wax Coating			
	1	254 (10)	1
Urethanes			
Acrylic urethane (i)	1	64 (2)	1
Acrylic urethane (ii)	1	64 (2)	1
Polyester urethane	1	64 (2)	1
Urethane elastomer (aromatic)	2	1,000-1,250 (39-49)	24
Urethane elastomer (aliphatic)	2	630-2,030 (25-80)	24
Urethane elastomer (coal tar)	1	760-1,000 (30-39)	16
Urethane (rigid)	1	380-500 (15-20)	Not effective
Urethane epoxy	1	380-500 (15-20)	24
Epoxies			
Polyamide epoxy (i)	1	76 (3)	1
Polyamide epoxy (ii)*	1	51 (2)	1
Polyamide epoxy (iii)	1	330 (13)	18
Polyamide epoxy (iv)	1	254 (10)	12
Blocked amine epoxy**	1	51 (2)	1
Aliphatic amine epoxy	1	114 (4)	6
MMB epoxy (i)***	2	254 (10)	12
MMB epoxy (ii)	2	305 (12)	12
MMB epoxy (iii)	2	254 (10)	48
Cycloaliphatic amine-A (i)	2	250-310 (10-12)	24
Cycloaliphatic amine-A (ii)	2	250-311 (10-12)	48
Aromatic amine (i)	2	250-312 (10-12)	24
Aromatic amine (ii)	2	250-313 (10-12)	12
Aromatic novolac amine (i)	2	250-314 (10-12)	Not effective
Aromatic novolac amine (ii)	2	250-315 (10-12)	Not effective
AHC (i)****	1	380-460 (15-18)	72 (12 hrs @ 30 C [86 F])
AHC (i)	1	1,000-1,500 (39-59)	Not effective
AHC (ii)	1	250-310 (10-12)	24
AHC (ii)	1	1,000-1,250 (39-49)	Softens in 48 hrs
Flexible AHC	2	>2,030 (>80)	18
Epoxy polysiloxane	1	102 (4)	12

*coating applied to, and stripped from, brick
 **coating applied to, and stripped from, rusted steel

***MMB-Modified aliphatic amine mannich base
 ****AHC-Advanced hybrid cycloaliphatic amine

quiring several hours of dwell time, applying the stripper later in the day and allowing it to sit through the night can prevent drying. The next day, the old coating can be successfully removed by scraper, squeegee, vacuum, or pressure washing (17 MPa [2,500 psi]). Should the latter be implemented, the most satisfactory results are achieved using a rotating nozzle.

For fast-track projects, chemical stripping can be enhanced when strippers are applied to heated substrates (32 to 66 C [90 to 150 F]). Under these conditions, coating removal can be started as soon as 30 minutes after the initial stripper application. Time to removal will depend upon (a) the coating's chemical resistance properties, integrity, temperature, and thickness, and (b) the chemical stripper type,

The application of strippers can also be used as a supplement to abrasive blasting. The substrate to be recoated can first be prepared with an application of a stripper, then abrasive blasted to speed up the retrofitting of projects. The volume of waste material would be significantly lowered (96-99% reduction) compared to the amount of waste generated by abrasive blasting alone.

PERFORMANCE TESTING OF CHEMICAL STRIPPERS

Four tests of the SARA stripper's effectiveness were conducted in the research for the original paper. Two of the tests are summarized here. All four are reported in the above-mentioned paper on which this article is based, and complete data are available therein.

The first experiment evaluated the capability of a SARA stripper to remove coatings applied to blast-cleaned steel. The second set of experiments evaluated the application and performance of surface-tolerant coatings applied to steel and concrete after chemical stripping of a previously applied coating.

Continued

Evaluation of SARA in Removing Coatings from Blast-Cleaned Steel

In the first experiment, a chemical stripper designated SARA-1 was applied to various coatings applied to blast-cleaned steel (Sa 2.5, SSPC-SP 10/NACE 1). The study determined the time to completely strip the coatings from the steel. Coatings tested included commonly used one- and two-component coatings and some special epoxy coating systems. The data are presented in Table 1. Some results are as follows.

Typically, latexes, alkyds, and two-component thin-film urethanes (DFT of 50-75 μm [2-3 mils]) were removed in one hour or less. A 10-coat alkyd system (DFT of 400-600 μm [15-24 mils]) was stripped in less than 18 hours. High-performance, thick-film elastomeric, rigid, and coal tar-modified urethanes (DFT of 400-2000 μm [16-18 mils]) proved more challenging but were still stripped in 24 hours or less. An epoxy polysiloxane coating (DFT of 100 μm [4 mils]) was stripped in less than 12 hours. An organic zinc and a calcium sulfonate wax coating were stripped in 6 hours and 1 hour, respectively (Table 1).

Stripping of a more chemical-resistant two-component epoxy was investigated as a function of curing agent and film thickness. Polyamide epoxies, modified aliphatic

amine Mannich base epoxies, a blocked amine, an aliphatic amine, and an aromatic amine were all stripped in less than 12 hours. However, longer times (approximately 48 hours) were required to strip epoxies with very high crosslink density. The SARA-1 stripper was found to be ineffective with some thin-film aromatic novolac amine-epoxies (DFT of 250-300 μm [10 to 12 mils]), thick-film advanced hybrid cycloaliphatic (AHC) novolac epoxies, and rigid polyurethanes.

Surface-Tolerant Penetrant Sealers on Rusted Steel, Mature and Green Concrete

The ability of SARAs to remove the coatings and provide an acceptable substrate for recoating followed previous work published in 1998 by the authors on characterizing the interface between surface-tolerant penetrant sealers and various challenging substrates.¹ Epoxy, moisture-cured urethane, polysiloxane, and methacrylate coatings were tested. In the 1998 work and the present work, the interface was tested for adhesion stress and examined to determine the micro-characteristics of the adhesion surface.

In the second set of experiments for the present work, surface-tolerant coatings were applied to the following:

Continued

- a) rusted panels;
- b) rusted panels in (a) from which the surface-tolerant coating was chemically stripped by three different SARAs and on which the coating was reapplied;
- c) abrasive blasted mature and green concrete; and
- d) mature and green concrete in (c) from which the surface-tolerant coating was chemically stripped by all three SARAs.

Three SARAs were evaluated: SARA-1 and SARA-3 were acidic and SARA-2 was alkaline. Initial strippability tests indicated that SARA-1 and SARA-3 would be the best performers, especially on concrete where their acidity could etch the alkaline cement paste to which the coating was bonded. Conversely, initial tests also indicated that the more alkaline SARA-2 would be least effective among the SARAs on epoxy coatings (noted for their alkali



Fig. 3: Optical micrograph of typical concrete after stripping



Fig. 4: Optical micrograph of rusted steel after stripping
Figures courtesy of the authors

resistance), and least effective on the concrete itself. (Test data are available in the original paper.)

Samples of steel and concrete coated in a previous study¹ were submitted to the action of the three SARA strippers for dwell times ranging from 1 to 48 hours. The samples of concrete were flatwork cast from the same mix design 2 years apart. The mature concrete was aged outdoors and coated after a dry summer. The green concrete was cured under burlap for three days, dried in air for three days, and coated on the seventh day after abrasive blasting. The concretes were nominal 30 MPa mixes with a W/C ratio of about 0.45, 5% entrained air, and 20-millimeter maximum-sized siliceous aggregate.

The steel samples were 6-millimeter (0.25-inch) plate steel that was pre-rusted by exposure to a 5-10 μm diameter distilled water fog (400 ml/m³/hr)

in a weathering chamber.⁸ All samples were coated about 12 months before being stripped.

After stripping, rinsing, and pressure washing with water, the samples were examined under the microscope to determine the effectiveness of the stripper, the quality of the resulting surface, and other notable phenomena. The samples were recoated and tested for adhesion of the same coating over the stripped substrate. Figures 3 and 4 are optical micrographs of typical concrete and rusted steel substrates after stripping. Adhesion testing was performed in accordance with ASTM D 4541, "Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers." Replicates were taken and averaged. Table 2 summarizes the adhesion testing on coatings re-applied to stripped surfaces.

A set of small cores was taken from the perimeter of some stripped areas for further microscope work. The cores were split, and thin sections were ground along radial cross-sections of stripped and unstripped inter-

faces to see the action of the stripper at the leading edge.

Actions of Strippers on Concrete

Chemical strippers SARA-1 and SARA-3 were effective and removed many of the coatings from the concrete—some rapidly. (Experimental data are available in the original paper.) The strippers were less effective on the green concrete than on the mature material. They were more effective on the thinner coatings than on the high-build epoxy and moisture-cured urethane coatings. Under the microscope, the partly stripped surfaces had remnants of the coatings primarily over the paste portions of the composite surface. It is thought that this phenomenon was caused by several factors.

- Because the paste portions were softer, they were therefore more deeply eroded by the abrasive surface preparation before the coatings were applied, and the coatings were therefore applied at greater thicknesses over the paste.
- The paste's being more porous than

the aggregate phase is therefore less effective as a substrate on which to develop the gaseous pressure required for release of the coating.

- There is less gas formation in the incipient stages of stripper-concrete contact, which results in less effective coating removal overall.

It is interesting that the coatings with good penetration into the paste were stripped quickly from the concrete surface, possibly because of the paste's being consolidated during the coating application, and definitely because the surface film builds were thinner. The reduced effectiveness of the stripper on the green concrete is almost certainly because of the rougher surface texture of this concrete after initial abrasive blasting.

Typical stripped surfaces of the concrete showed clean aggregate protruding through the cement paste. Concrete surfaces stripped by SARA-1 and SARA-3 showed varying degrees of surface etching and a residue of chemically affected paste between aggregate

Continued

Table 2:
Adhesion Values on Coatings Applied on Concrete and Rusted Steel Before and After Stripping with SARA-1 and Recoating with the Same Coating

Coating Code	Generic Type	Viscosity Ford #4 Cup seconds	Film Thickness μm (mils)	Adhesion Value, MPa (psi)					
				Rusted Steel	Rusted Steel Recoated	Mature Concrete	Mature Concrete Recoated	Green Concrete	Green Concrete Recoated
A	EPS	13	102 (4)	4.9 (711)	3.7 (537)	3.2 (464)	5.5 (798)	2.6 (377)	4.7 (682)
B	EPS	17	112 (4)	2.6 (377)	4.8 (696)	2.9 (421)	2.2 (319)	3.2 (464)	2.4 (348)
C	EPS	334	229 (9)	—	3.4 (493)	3.0 (435)	—	2.4 (348)	1.2 (174)
D	EPS	54	165 (6)	2.2 (319)	6.9 (1,001)	3.0 (435)	1.4 (203)	3.7 (537)	1.4 (203)
E	EPS	49	188 (7)	1.0 (145)	2.1 (305)	2.7 (392)	3.4 (493)	2.6 (377)	4.1 (595)
F	MCU-PS	192	279 (11)	0.9 (130)	—	1.6 (232)	5.3 (768)	2.7 (392)	—
G	MCU-PS	180	226 (9)	1.2 (174)	—	2.4 (348)	1.2 (174)	3.0 (435)	1.9 (276)
H	MCU-PS	63	201 (8)	3.3 (479)	2.4 (348)	2.4 (348)	4.1 (594)	2.5 (363)	4.1 (595)
I	E-Polys	38	193 (8)	2.4 (348)	—	3.3 (479)	2.8 (406)	3.7 (537)	1.0 (145)
J1	Epoxy-HB	43	241 (9)	3.4 (493)	2.1 (305)	2.8 (406)	2.1 (305)	3.9 (566)	1.4 (203)
J2	Epoxy-HB	14	340 (13)	5.5 (798)	—	3.0 (435)	—	2.5 (363)	—
K1	Epoxy-HB	16	264 (10)	4.1 (595)	2.6 (377)	4.0 (580)	1.2 (174)	2.9 (421)	1.4 (203)
K2	Epoxy-HB	10	340 (13)	4.7 (682)	2.8 (406)	3.6 (522)	1.4 (203)	2.7 (392)	2.6 (377)
L1	Epoxy-HB	45	203 (8)	2.2 (319)	0.7 (102)	2.6 (377)	—	2.5 (363)	—
L2	Epoxy-HB	17	—	2.0 (290)	—	4.8 (696)	1.4 (203)	4.4 (638)	1.0 (145)
M	Methacrylate	8	25 (1)	5.2 (754)	—	3.4 (493)	—	2.7 (392)	—

Key: EPS: epoxy penetrant sealer MCU-PS: moisture-cured urethane penetrant sealer E-Polys: epoxy polysiloxane Epoxy HB: high-build epoxy Methacrylate: modified methyl methacrylate

particles. Analysis of the paste residue by Quantitative X-Ray Diffraction (QXRD) in the electron microscope showed it to have been leached of calcium by the stripper, in a similar manner to paste exposed to strong acid.

The depth of the etching was measured by exposing a concrete surface (ground flat) to the strippers for increasing periods of time between 1 and 48 hours (Figs. 5a-c). It is noteworthy that after 6 hours of contact,

SARA-1 produced a profile of 50 μm (2 mils) in the concrete, the same profile developed by 15 minutes of contact of concrete with 1M HCl. In contrast, SARA-2 did not etch the concrete even after 48 hours' contact.

Table 2 shows the adhesion of the coating to the mature and green concrete with the original coatings and the adhesion after the coatings were stripped and re-applied. The adhesion after re-application ranged from fair to excellent (1.2 to 5.5 MPa [174 to 798 psi] for mature concrete and 1.0 to 4.7 MPa [145 to 682 psi] for green concrete).

Actions of Strippers on Rusted Steel

The strippers generally had greater effectiveness in removing existing coatings from the steel substrates than from the concrete. Furthermore, steel surfaces were for the most part completely stripped in less time than the



Fig. 5a: Electron micrograph of lapped concrete surface used as a control in the etching test



Fig. 5b: Electron micrograph of concrete surface etched with 1M HCl for 15 minutes. The raised areas are siliceous aggregate particles while the depressions are cement paste etched by acid



Fig. 5c: Electron micrograph of lapped concrete surface etched by SARA-1 (6-hour exposure). This surface had been pressure washed at 2 MPa to remove loose material

Figures courtesy of the authors

CASE HISTORY—STEEL SUBSTRATE— LPG PROCESSING AND STORAGE FACILITY

The effectiveness of chemical stripping in conjunction with surface-tolerant coatings was demonstrated in an environment where abrasive blasting could not be performed.

At a multinational oil company's LPG plant in Alberta, Canada, a chemical stripper was successfully used to remove the existing 20- to 25-year-old multi-coat paint system from one header (on a manifold of 13 such headers). A header is a complex configuration of piping (25-200 mm in diameter [1-8 inches]), numerous valves, moisture traps, instrumentation, and other automatic controlling devices. It is one component of a system in which LPGs are placed into, or extracted from, large naturally formed underground caverns.

The removed coating was replaced with a surface-tolerant coating system. Abrasive blasting was not viable because of extreme explosion hazards and the impracticality and prohibitive expense associated with shutting down key operating areas within the facility. Before the actual stripping activities began, the selected header was contained with protective tarps. This was done to contain all stripping materials; materials subsequently stripped; and paint overspray. The containment also protected newly applied coatings should inclement weather occur. Cheese cloth

(#10 mutton cloth, an extremely fine mesh) was placed on the gravel covered ground, within the contained area, to ensure that all coating materials removed from the header were recovered and could be disposed of in accordance with local regulations. The SARA stripper, being 100% biodegradable in soil in 100 days, passed through the cheese cloth with the water used in the pressure washing process and was allowed to biodegrade naturally. All paint was collected.

Over the years, multiple coating applications on valves and other appurtenances had led to extremely high film thickness readings (DFT of 230-900 μm with 400 μm average [9-33 mils with 16 average]). At the time of the initial application of the stripping materials, ambient temperatures were between 17 and 18.3 C (63 and 65 F), and substrate temperatures ranged from 10 to 15.5 C (50 to 60 F).

Using a 45:1 airless pump (3-19 tip), two applicators applied the SARA chemical stripper to the header at wet film thicknesses of 200-250 μm (8-12 mils) to an area in excess of 200 sq ft (20 sq m) in less than 30 minutes. For maximum efficiency, the output pressure of the pump was set so that only an adequate spray fan was achieved; higher pressures tended to blow the stripper off the surface. Figure A shows the applied stripper on the header components inside containment.

concrete. The probable reason for this is that the more even coating thickness and solid backing to the coating allowed a more effective action of the gaseous agent.

It is interesting to note that upon re-coating, coatings B, D, and E exhibited increased bond strength to the substrate. Pull-off tests resulted in the coating on these samples removing substantial portions of the consolidated rust. The improved adhesion values in these samples seem to be due to the adhesive bond of the coating to the abrasive blasted steel surface exposed under the rust. Rust was not removed on samples with coatings that did not penetrate the rust (action of stripper did not lift unconsolidated rust), and adhesion on these samples was generally reduced after stripping when they were recoated with the same coating.

SARA-2 on both steel and concrete

was generally less effective than the other two strippers. This stripper is alkaline and does not generate gas at the interface.

GENERAL DISCUSSION OF SURFACE-TOLERANT COATINGS COMPLEMENTING SARA STRIPPERS

In the 1998 study by the authors,¹ 13 proprietary surface-tolerant coatings (A-M) representing a cross-section of generic types were investigated for their ability to impregnate porous surfaces. The same coatings were used in the present study (Table 2). The study included five unpigmented two-component epoxy penetrant sealers (EPS); three pigmented single-component, moisture-cured urethane penetrant sealers; three two-component high-build epoxies; a methacrylate; and a polysiloxane. Curing agent choice

among the epoxies was important with respect to penetrant sealer characteristics since the curing agent helps determine a coating's viscosity, pot life, dry time, and molecular mobility for both high penetration/wetting and low stress development. This investigation by the authors on surface-tolerant coatings applied to rusted steel and concrete panels led to the following conclusions.

- A blocked amine surface-tolerant epoxy penetrant sealer (A), two other low viscosity epoxy sealers (B and E), a moisture-cured urethane (H), and a nearly water-thin modified methacrylate sealer (M) demonstrated the best penetration action in the test and consolidated the porous surfaces well.
- No surface-tolerant primer completely impregnated loose rust or highly porous surfaces. However, the best

Continued

Within ten minutes of stripper application the coatings lifted noticeably. However, the top layers of the coating on the underside of the pipe sagged such that coating layers beneath them were unable to come in contact with the stripping material. Figure B shows the coating lifting after 10 to 15 minutes. After a 1-1/2 hour dwell time, all loosened material was removed from the header by fresh water pressure washing at 17-21 MPa (2465-3045psi) as shown in Fig. C. After the header had dried for 10 minutes at ambient temperature, a second layer of stripper was applied and allowed to remain overnight on all designated surfaces.

The following day, approximately 90% of the original coating that had remained after the first application had been successfully lifted. On several small areas, insufficient amounts of stripping material had been applied, and the stripper had dried out overnight. The entire header was pressure washed. Approximately 3 to 5% of tightly adherent paint still remained and was deemed suitable for overcoating with a penetrating sealer. These areas were hand-sanded and feathered into the bare steel to ensure that no cut line (imprint) would be visible in this transitional zone once the refreshment coating system had been applied.

After this minimal surface preparation, appurtenances not to be painted were masked. Stripped surfaces were spray-applied with a 100% solids, low viscosity, blocked amine, epoxy penetrant sealer at DFTs of 25-38 μm (1 to 1.5 mils).

The following day, the prime coat of surface-tolerant, modified Mannich base (MMB) epoxy was applied at DFTs of 125-180 μm (5 to 7 mils). Because of the onset of inclement weather, a finish coat of acrylic polyurethane was applied five days later (Fig. D) at DFTs of 50-75 μm (2 to 3 mils). The new coating system was aesthetically pleasing, and its DFT was in the range of 230-360 μm (9-14 mils). After one year, the system was performing well, the owner reported.



Fig. A: SARA-1 stripper applied, lifting and removing existing coating system



Fig. B: Coating lifting after 10-15 minutes dwell time



Fig. C: Removal of existing coating by pressure washing at 17 MPa
Photos courtesy of the authors



Fig. D: Complete project after application of 50-75 μm DFT of aliphatic urethane topcoat

coatings displayed considerable ability to penetrate cracks and consolidate friable material at rusted steel and concrete surfaces.

In the work reported here, the behavior and penetrating abilities of these previously studied surface-tolerant coatings (e.g., for rust and mature and green concrete) were compared to their behavior on a surface subjected to the action of chemical strippers. Optical microscopic photography was used to study coating penetration. The nature of the micro-environment at the steel- and concrete-coating interfaces was of great interest because strippers don't leave behind perfect Sa 2.5 type finishes. The surface-tolerant coatings therefore play an important role in the adhesion characteristics on such stripped surfaces.

The present investigations have shown that the use of a surface tolerant coating before recoating with high-build coatings can provide good adhesion to surfaces prepared with chemical strippers. This finding is consistent with observations of the industrial applications of high-performance coatings on concrete floors. The use of epoxy penetrant sealers thoroughly wets out the concrete prior to the application of high-build epoxies and therefore provides greater adhesion for the overall system.

In the 1998 work, the authors found that low viscosity

epoxy penetrant sealers and certain moisture-cured urethanes demonstrated the best penetration and consolidation of porous rusted steel and concrete surfaces. In the present work, the same low viscosity epoxy penetrant sealers and moisture-cured urethanes also show the best consolidation and penetration over the chemically stripped surfaces. Data are available in the original paper on which the present article is based.

Cost comparison between the use of conventional chemical strippers and more conventional means of coating removal is complicated by several factors. For example, dwell times and stripping efficacy will depend on the generic type and thickness of the coating, the environment (indoors, outdoors, inside a tank, etc.) as well as upon the configuration, temperature, and composition of the underlying substrate.

However, coating removal with SARAs can offer substantial cost-savings. There are no dust or solvent vapor containment requirements, and so containment costs are dramatically reduced or eliminated. Moreover, unlike the case for many bond breakers and caustics there are dramatically minimized costs associated with SARA-contaminated waste as well as lower insurance premiums due to

Continued

storage of non-toxic chemicals (SARAs do not add to the toxicity of the paint or coating waste). Smaller and less expensive equipment is required and there will be markedly less or no substrate damage. And without facility shut-downs or disruptions of other trades, work can readily be carried out by onsite contractors, or fa-

cility personnel, even in hazardous environments.

Quantifying the cost savings associated with SARA chemical strippers therefore requires an assessment of not only the lower and direct application savings but indirect savings accrued by the facility owner.

SUMMARY

Selective adhesion release agents (water-borne macro-emulsion SARA technology) are a new generic class of chemical strippers. They are economic, safe for workers and the environment, and effective on a variety of generic coatings.

A three-phase mechanism has been elucidated for the stripping action of SARAs. The latter involves a rapid pressure transition as a result of gas formation at the coating-substrate interface.

In architectural, industrial, and marine environments, the use of SARAs, in tandem with surface tolerant coatings, is often a viable approach for removing coatings applied to ferrous and non-ferrous substrates.

Use of surface-tolerant coatings that penetrate and consolidate surfaces prepared with SARAs has proved to be a good method of providing satisfactory to excellent adhesion for the recoating material (or new coating system application) to the prepared substrate. The mechanism at work in this instance is the same as that observed in coating over loose rust and abrasive blasted concrete surfaces: low viscosity coatings that have good wetting ability perform this task well while high-build coatings, even when thinned, rarely penetrate the surface enough to adhere sufficiently well to solid substrate material.

It is suggested that the currently used generic category of chemical strippers known as bond breakers be reclassified as "stress-inducing release agents" and that the current category of caustics be reclassified as "bond breakers."

REFERENCES

1. M. O'Donoghue, R. Garrett, V.J. Datta, L. Peer, "Penetrating Sealers: A Comparison of Epoxy, Moisture-Cured Urethane, and Siloxane Technology on Concrete, Rust, and an Inorganic Zinc Coating," *JPCL* (December 1998), p. 30.

2. J.V. Koleske, *Paint and Coating Testing Manual (Gardner-Sward Handbook)* (Philadelphia, PA: ASTM, 1995), p. 513.
3. SSPC-TU6: Chemical Stripping of Organic Coatings from Steel Structures, SSPC Publication No. 99-09, ISBN 1-889060-37-2 (Pittsburgh, PA, U.S.: SSPC, 1999).
4. C.H. Hare, "Effects of Solvents on Coating Films," *JPCL* May 1997, p. 69.
5. G. Snyder, Sam Visaisouk, and J. Steihauser, "Ice Blasting and Chemical Stripping: A Marriage of Technologies for Cost-Effective Lead Paint Removal." *The Proceedings of the SSPC 1998 Seminars*, Orlando, Florida, Nov. 15-19, 1998 (Pittsburgh, PA, U.S.: SSPC, 1998).
6. U.S. Patent #5728666 and other patents pending.
7. S. Vitomir, D. White, M. O'Donoghue, Unpublished research at Napier International Technologies Inc., December, 1999.
8. International Electrotechnical Commission Weathering Chamber, IEC 1109

- Buick Sandblasting Ltd. for original surface preparation and coatings applications;
- Vancouver Petrographics Ltd. for thin sections;
- Bacon Donaldson Coast Testing Ltd. for SEM and optical microscopic work;
- Mills Paint Ltd. for viscosity measurements;
- Mssrs. Peter Roberts, Bob Avery, and

- Jamie Garrett of ICI Devoe Coatings for adhesion testing;
- R.P. Richmond Ltd. for steel panel surface preparation; and
- Mr. Paul Slipchuk of Dragon Sandblasting Ltd. for his contribution to the case history; and
- various coating manufacturers for providing samples.

ACKNOWLEDGMENTS

The assistance of the following is gratefully acknowledged:

- AGRA Earth and Environmental Ltd. for the mature concrete samples from their archive and sample cutting;
- Lafarge Construction Materials for the green concrete panels;
- Powertech Laboratories for rusty panel preparation;

Send articles on research in coatings, surface preparation, and other topics related to high-performance maintenance coating work to

Karen Kapsanis, Editor, *JPCL*
 2100 Wharton St.
 Suite 310
 Pittsburgh, PA 15203
 +1/800/837-8303 (U.S. and Canada)
 +1/412/431-8300
 fax: +1/412/431-5428
 e-mail:
 kkapsanis@protectivecoatings.com

This article was published in the *JPCL* (May, 2000) and is reprinted here with permission of the publisher, Technology Publishing Company, Pittsburgh, PA, which holds the copyright. Publication without explicit permission from the publisher is not allowed. To read more articles from *JPCL*, go to www.paintsquare.com.