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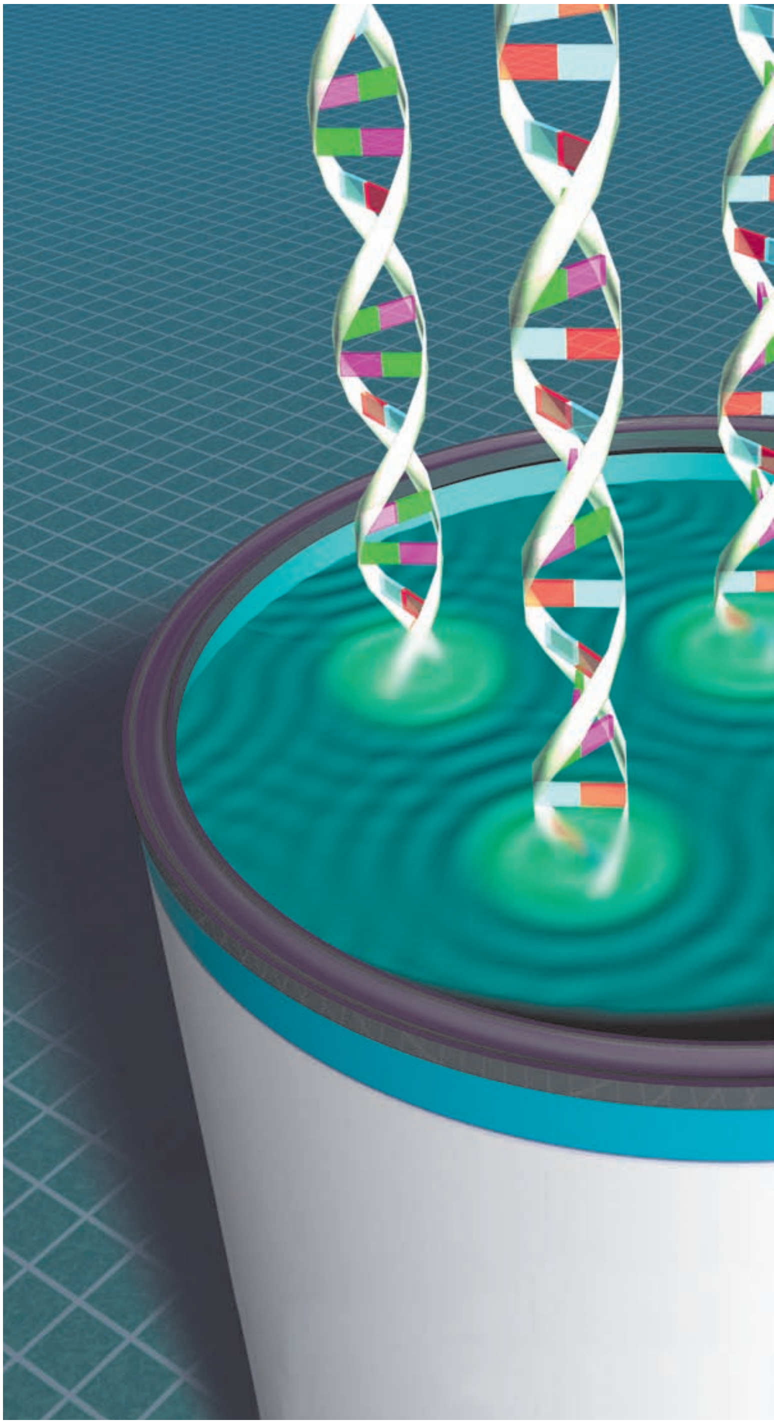

In the second of a three-part series discussing the potential for bio-functional coatings to serve as catalysts for revitalizing the coatings industry, the characteristics, mode of action and formulation issues associated with several novel bioengineered additives are reviewed.

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To maintain innovation, create value and stem the tide of increasing commoditization where only price differential distinguishes competitive product offerings in the paint and coatings industry, formulators must find innovative methods to add measurable value to their products (*see, "Functional Additives: A Platform for Revitalizing the Paint and Coatings Industry," Coatings World, February 2010*). Any new technology that may reverse commoditization must be easily implemented by manufacturers and customers in order for its impact to be swift and significant. Incorporation of novel functional additives enables the development of paints and coatings that possess unique performance characteristics in addition to their ability to protect and beautify. Not only will functional coatings find widespread use in traditional applications, but demand from yet unexplored end-use markets will create additional growth opportunities.

The term "functional coating" encompasses numerous formulation types that serve a specific purpose not expected from traditional materials. In some cases, the resin itself imparts the added functionality. In most instances though, specialty additives with the capability to initiate targeted environmental, chemical or biological processes provide the desired activity. Regardless of the means of functionalization, coatings that destroy microbes, sense and report internal damage, self-repair, self-clean, catalyze chemical reac-

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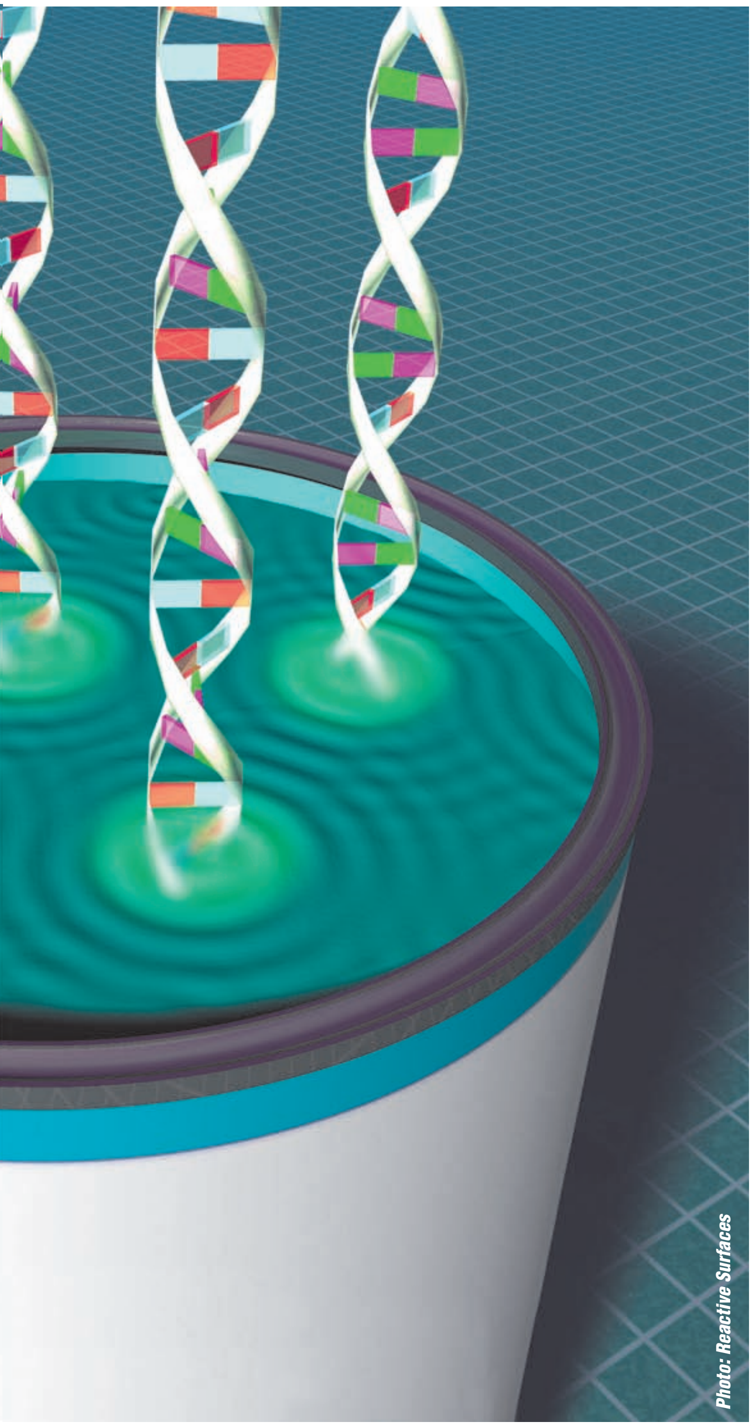


Photo: Reactive Surfaces

tions or increase structural integrity are, or soon will be, available to formulators.

CHOICES, CHOICES, CHOICES

Much of the research on functional coatings to date has focused on the development of novel additives that perform defined tasks once they are incorporated into the film. Such additives include not only engineered biomolecules such as proteins and enzymes but also nanomaterials and encapsulated specialty chemicals.

When reduced to the nanoscale, certain substances (nanomaterials) exhibit unique chemical and physical properties and are capable of enhancing coating performance in a number of ways. Magnetic, antimicrobial, antistatic, photocatalytic (self-cleaning), optical, surface energetics and many other attributes can be enhanced or affected with the use of nanomaterials. Many companies have commercialized products for the industry in pursuit of such benefits.[1] The unique nature of nanomaterials, however, has raised concerns about the potential environmental, health and safety hazards they might present. Some early studies on carbon nanotubes have underscored this concern.[2] Both the European Commission and the U.S. Environmental Protection Agency (EPA) have initiated programs to investigate this issue.[3]

While nanomaterials have attracted much interest from academia and industry, many researchers have elected to explore new mechanisms for incorporating more traditional materials as functional additives.[4] One technique is to encapsulate these materials—often monomers, catalysts, dyes or pigments—in microcapsules that are designed to trigger/degrade under certain conditions. Upon their release, the additives undergo a chemical reaction or physical response to the conditions that initiated the capsule decomposition. Other additives have been incorporated to indicate changes in the coating as opposed to repairing or maintaining functionality. Such indicators may include thermochromic, photochromic and piezoelectric pigments, which have been designed for use in paints as sensors. Passive functional materials have been included to guard against microbial attack such as specially designed silver, calcium hydroxide and titanium dioxide.

The use of such additives shows great promise, but there are limitations. Functional materials for use in paints and coatings must be carefully selected to meet a number of criteria. Specifically, such additives must:

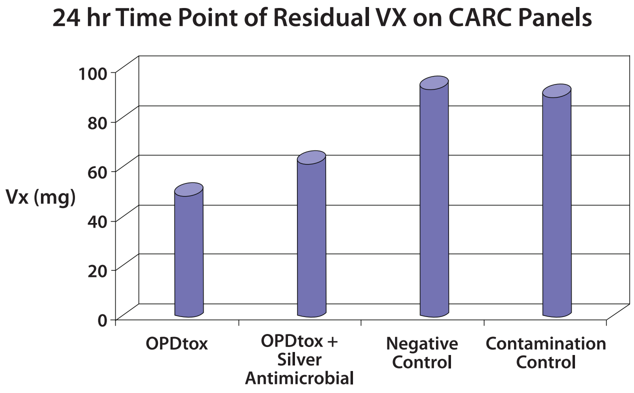
- be compatible with the other coating ingredients;
- have little or no impact on general coating performance;
- survive the production process;
- be stable under typical storage conditions on the shelf and in the film;
- consistently respond to relevant stimuli; and
- repeatedly respond to stimuli within a commercially-reasonable time frame.

With the growing market demand for "greener" coating products, these additives as well as their manufacturing processes must also be environmentally friendly. Engineering such products can be a challenge.

NATURALLY THE BEST CHOICE

Biomolecules—also referred to as biocompounds, biocomponents or bioadditives—represent a third class of functional additives that meet all of these criteria as has been demonstrated by a number of researchers in both industry and academia. Biocompounds, such as peptides and proteins, with the potential for use as functional additives are well known and have been used for many years in a variety of industries outside paint and coatings such as detergent enhancement additives, tanning processes and food processing. In addition to being biodegradable, bioengineered additives operate under mild conditions, produce no toxic

Figure 1



NATO study results of CARC panels aged for 14 months or more, when challenged with neat weapon-grade VX.

byproducts and exhibit highly targeted modes of action. They can be produced using methods long employed by the biotechnology and fermentation industries, making them readily scalable. Furthermore, very recent research has demonstrated that when properly prepared, biomolecules are stable in paint formulations and retain their activity for extended periods of time, both in-can and in-film.

One of the main challenges in this field is to decide upon which functionality to focus. With so many different natural materials to choose from, and so many different ways to modify the activity of individual biocompounds, the initial decision can be difficult. Enzymes, peptides and proteins, antibodies, viruses and even whole cells and cell parts have been investigated. Different mechanisms of incorporating the bioadditives have also been explored including simple mixing or blending into the paint or coating formulation, chemical attachment to the binder prior to formulation and even attachment to the surface of preformed films. The desired functionality, specific paint formulations and end-use will dictate which specific biocomponent and incorporation technology is best suited for any given application. Bioengineered additives can be custom tailored using molecular biology techniques to provide maximum performance for each unique set of conditions.

ENZYMES

Enzymes catalyze biochemical reactions in living systems. Comprised of long sequences of amino acids, the unique three-dimensional arrangements of the amino acids in each enzyme impart a specific reactivity. For some enzymes only certain chemical transformations will be mediated for a set of reactants (substrates), while for others a broad range of robust reactions can be catalyzed in forward and reverse directions. The optional selectivity allows for either tightly controlled or broad functionality, depending on the desired functional outcome. At the same time, there are many types of enzymes from which to choose, enabling the development of paints and coatings with a wide range of functionalities.

Incorporating enzymes into certain polymeric materials was first investigated in the late 1970s.[5] Since that time, much has been learned about manipulating enzymes under such conditions and the performance of many different types of enzymes has been investigated. For example, biocatalytic plastics with potential use in organic synthesis have been reported.[6] ICx Technologies has developed methods for preparing enzyme-polymer hybrids and conjugates for numerous applications.[7] Several different groups have reported on efforts to develop marine anti-fouling paints containing enzymes. One approach involves incorporation of hydrolytic enzymes into low-surface energy polydimethylsiloxane coatings to provide a dual mechanism for reducing attachment of marine organisms.[8] Others have investigated the use of proteases, lipases, oxidases and many other enzymes in paint to either directly or indirectly affect the ability of microorganisms to attach to the submersed marine surface.[9]

To date, the class of enzymes known as hydrolytic enzymes have been the most widely investigated as potential bioengineered additives for functional coatings. Organophosphorus hydrolases, carbamate hydrolases, haloalkane dehalogenases, and serine proteases, for example, have been shown to degrade various chemical warfare agents, pesticides and harmful microbes.[10] A NATO group (BToE-HSMG) tested metal coupons coated with military (CARC) paint formulations containing OPDtox additive from Reactive Surfaces against the nerve weapon VX.10 Different formulations containing the immobilized enzyme degraded 16-41% of the toxic material in a 24-hour period, and the results were deemed to be "quite promising" as a secondary decontamination method for military airframe surfaces (*see Figure 1*).

OPDtox contains organophosphorous hydrolase, an enzyme that specifically cleaves the P-0, P-F and P-S bonds in organophosphorous compounds, producing non-toxic byproducts.[11] The enzyme exhibits both thermal and conformational stability and has been shown to retain activity for many months, both in storage as a dry powder and when incorporated into a paint film under diverse conditions. Reactive Surfaces has successfully challenged coatings containing OPDtox with a number of different chemical warfare agents and pesticides and has shown that even after a year or more, applied coatings still degrade OP substrates at a reasonable rate.[12] Even if arid conditions are maintained for extended periods (> 14 months), the coating, and immobilized enzyme, will function optimally once rehydrated.

Hydrolytic lipases have been explored by Reactive Surfaces as additives for self-synthesizing coatings.[13] Poly(methyl methacrylate) (PMMA) films containing porcine pancreas lipase, octanoic acid and 1-nonanol were formed from a toluene solution in glass dishes and incubated for 250 hours at 40°C. Synthesis of the desired ester occurred, with the highest conversion taking place in the thickest film, indicating that the reaction proceeded throughout the coating and not just on the surface. The same enzyme, when incorporated into an emulsion-based paint, was shown to catalyze ester hydrolysis.[14] In this case though, the reaction took place on the surface only. These results confirm that by understanding how polymer matrices impact and drive enzyme reactivity, it is possible to design highly functional and even multi-functional coatings.

The Reactive Surfaces product DeGreez contains lipases as the active biocomponent. Coatings containing DeGreez are capable of catalyzing the breakdown of natural greases, fats and oils, known as triacylglycerols, via ester hydrolysis (*see Figure 2*). This class of enzymes has been used for many years in the food, detergent and pharmaceutical industries, and the biotechnology to produce them is readily available.

Paints and coatings containing hydrolytic enzymes have many potential applications. In addition to those described above (decontamination, self-healing, chemical catalysis, marine anti-foulants), there is at least one example of a bioactive coating patented for in use in a medical device.[15] Such bioengineered coatings have also been investigated for food packaging applications.16 Oxidases, particularly glucose oxidase, have also been investigated as antimicrobial agents[16,17] and oxygen scavengers[18] for food preservation.

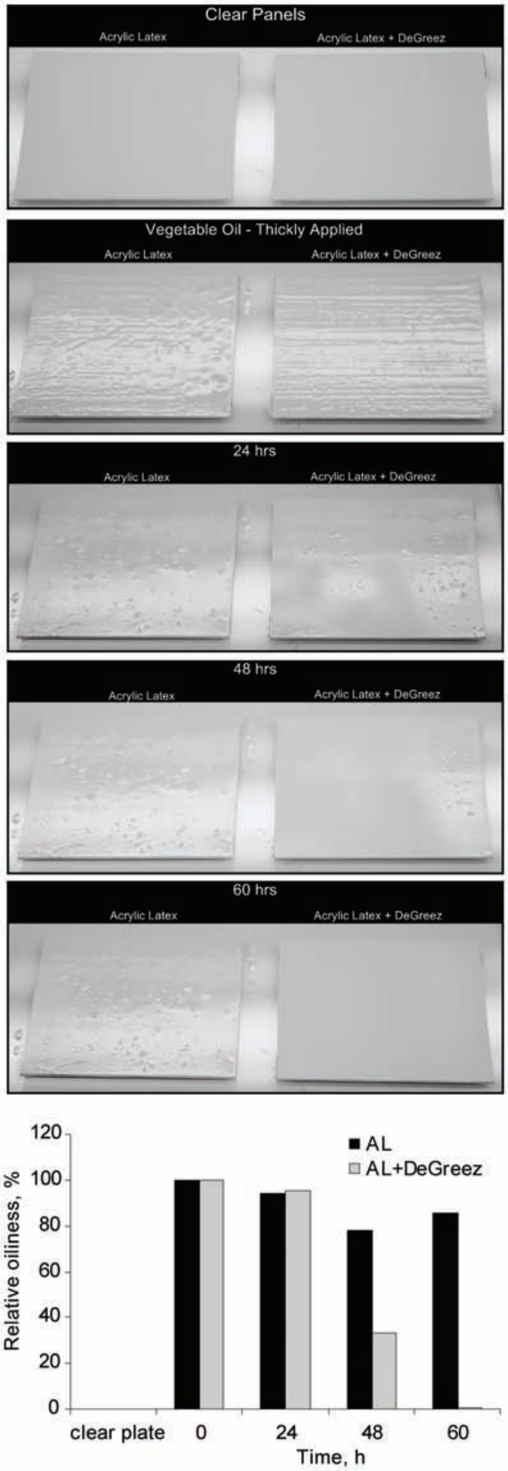
PEPTIDES AND PROTEINS

Like enzymes, peptides—and larger, non-catalytic proteins—are comprised of a specific sequence of amino acids, but are much shorter in length. These smaller biomolecules have unique structures and play important roles in many different biological mechanisms. As with the enzymes, they too have significant potential as bioengineered additives in paints and coatings. Two companies—Marical and Reactive Surfaces—have been successful in identifying promising candidates in this category.

Marical has incorporated modulators of Calcium Sensing Receptor (CaSR) proteins into paint formulations that are linked to the settling behavior of various invertebrate marine organisms.[19] When these modulators bind to the CaSR, different activities such as selection of a settlement site, attachment to a site, and even metamorphosis and growth are altered by changing the expression, sensitivity, activity, signaling and/or physiological function of the receptor.

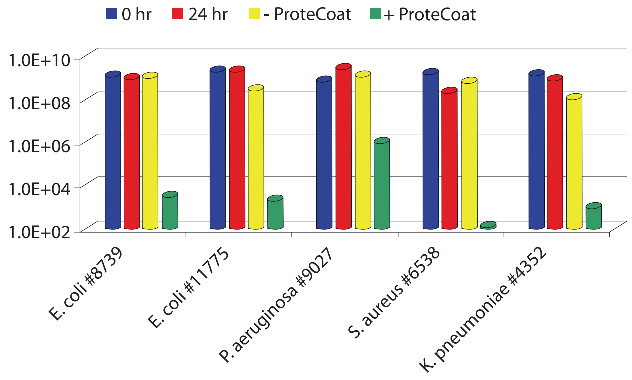
Reactive Surfaces has bioengineered antimicrobial peptides for incorporation into paint formulations and offers them through its ProteCoat product line. These antimicrobial peptides (AMPs) are designed to selectively target the cell membranes of microorganisms as opposed to cell membranes of plants and animals.[20] Microbial cell membranes contain negatively charged lipids generally lacking in the outer membranes of plants and animals. AMPs interact with the negatively charged lipids, disrupting the cell membrane and ultimately killing the microorganism. With this mode of action, AMPs target characteristics common to microorganisms and thus offer true broad spectrum activi-

Figure 2



Lipolytic coatings created by blending DeGreez additive with Glidden Vinyl latex (1424). The time course of reactivity flows from the top to bottom with the control panel on the left and the reactive panel on the right. The decrease in surface fouling oil is obvious over time, and is quantitated by surface albedo in the bar graph following the last digital image.

Figure 3



Glidden Vinyl Latex coated paper swatches with and without ProteCoat testedagainst five different bacterial isolates of interest in coatings.

ty against many different types of bacteria, yeast, mold, fungi and some viruses and algae.

The effectiveness and general applicability of ProteCoat AMPs in paint formulations has been tested in a variety of formulations against a variety of microorganisms and under a variety of conditions. In one test, the additive was mixed with the styrene-acrylic emulsion polymer UCAR 451 from the Dow Chemical Company and painted onto the bottom of sample wells.[20] Each well was exposed to a solution containing spores of three different microorganisms: *Aspergillus nididans*, a model for *A. fumigatus*, a potentially fatal human pathogen; *Bacillus atrophaeus*, a non-toxic analog used by the U.S. military for the anthrax-producing *B.cmthracis*; and *Fusarium oxysporum*, a plant fungus and potential human pathogen.

ProteCoat exhibited activity against all three microbes, confirming that AMPs retain their broad spectrum antimicrobial functionality when added to cured films. The product can also be applied separately to the top of an already applied coating and is slightly more effective this way than when mixed into the paint.[20b] In other tests, ProteCoat proved to be effective against clinically-important bacteria when incorporated into a vinyl latex and used to coat paper discs. The bioadditive was shown to reduce by 5-6 logs the contamination of five different strains of bacteria (*see Figure 3*). In tests of exterior architectural coatings, ProteCoat was shown to significantly reduce the microbial growth on an unprimed flat latex used to coat cedar paint fence panels over an 18-month exposure while north facing at a 90° incline (*see Figure 4*).

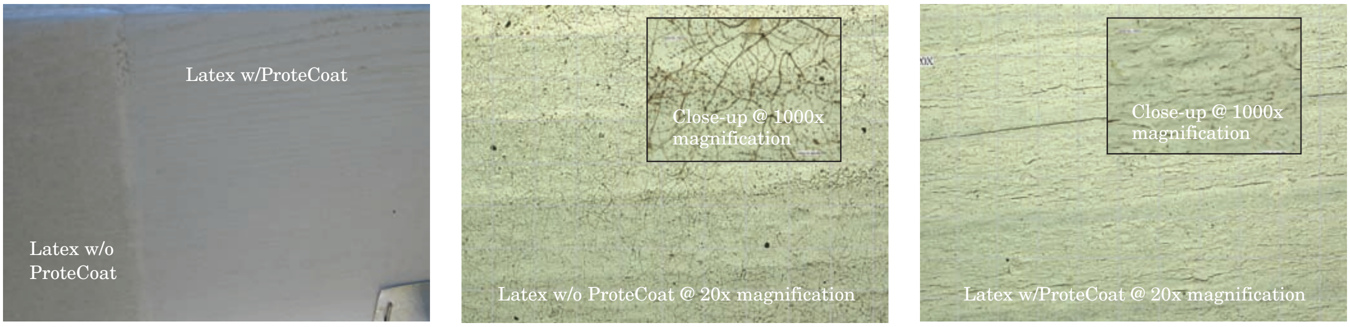
Another attractive characteristic of AMPs is their ability to work synergistically with traditional biocides and other enzymes. Antimicrobial peptides attack and weaken the cell membrane of microorganisms and make it easier for other biocides to penetrate the microbes and thus increase their effectiveness. Tests with in-can preservatives 2-methyl-4-isothiazolin-S-one and dodecylguanidine and infilm preservative 3-iodo-2-propynyl butyl carbamate show that ProteCoat does increase the efficacy of conventional biocides even at concentrations below 1%.21 When used in combination with Verichem's N-2000 biocide, Protecoat reduces by over 60% the amount of the traditional biocide needed to kill the test microorganism (*see Figure 5*). The ProteCoat AMP product has also been shown to significantly increase the efficacy of enzymatic antimicrobial additives.[22]

ANTIBODIES, VIRUSES AND CELLS

More recently, researchers have begun to explore the possibility of incorporating other active bioadditives into paints and coatings, including antibodies, viruses and both whole cells and parts of them.

Antibodies are gamma globulin proteins that detect and destroy bacteria, viruses and other foreign objects. Each anti-body has a unique structure at the tip of the protein called the antigen binding site that is designed to target a specific antigen—typically a virus or bacterium. Due to the nearly endless possible variants of the antigen binding site, antibodies can be created to target and bind a vast number of potential pathogens or other problem molecules. In the body, the antigen, once bound by the antibody, is marked for destruction by other biochemicals in the immune system.

Figure 4: Unprimed flat latex on cedar with ProteCoat, facing North @ 90˚ after 18-month exposure



Eighteen-month fence panel testing of exterior latex coatings with and without ProteCoat, side-by-side comparison (leftmost side without rightmost side with ProteCoat); the images at right are close ups—including microscopic microbial growth photographs—of the same panel.

In a paint and coating formulation, antibodies could behave similarly, binding contaminants that come in contact with the surface and leaving them exposed to attack by other actives designed for that purpose. Researchers at the University of Pittsburgh have developed coatings containing both antibodies and enzymes.[24] Antibodies for pathogens such as anthrax and smallpox have been incorporated into the paint, with lysozyme enzymes present to destroy the bacteria once bound by the antibody.

Viruses, cells and cell parts have been investigated as independent actives as well as vehicles to deliver biofunctional additives. For example, the OPDtox additive produced by Reactive Surfaces has as its active component the bacterial enzyme organophosphorous hydrolase (OPH). The gene for the enzyme was modified to produce an enzyme suitable for use as an additive in a coating. When the gene is placed into a bacterial host cell (*E. coli*), the enzyme can be manufactured in high concentrations via a fermentation process. Once the fermentation process is completed, the resulting whole cells of bacteria are subjected to commercial spray-drying, which ruptures the cells and exposes the OPH enzyme active. The fine powder that results is readily incorporated into many paint formulations. Delivering the enzyme active in this fashion greatly enhances the thermal stability of the enzyme in the applied film (*see Figure 6*).

FORMULATING THE ADDED BENEFITS

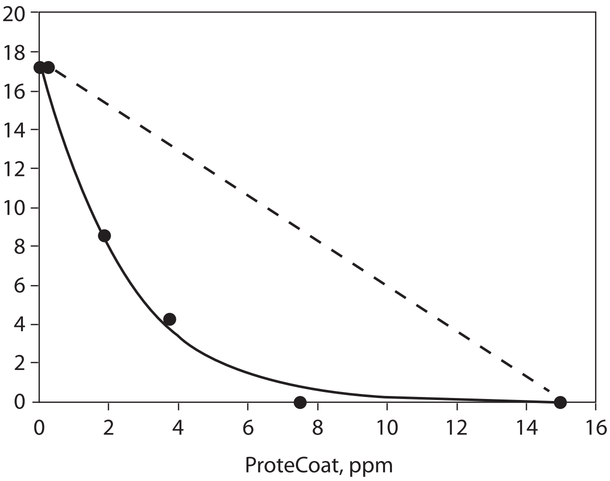
As researchers have investigated the viability of incorporating bioactive compounds into paints and coatings, it has become clear that the method of biomolecule inclusion is critical for determining not only the level of activity and stability, but even the type of reactivity. At the same time, it has been shown that bioengineered additives can indeed be successfully formulated into paints and coatings to produce materials that provide a variety of active functions and responses along with protection and decoration.

The first step when developing a biofunctional coating is selection of a biocompound that exhibits the desired activity and has a high likelihood of performing well in a coating formulation. Therefore, not only the specific reactivity of the bio-molecule, but its compatibility with the polymer in terms of its physical and chemical properties, and the functionality of the bioactive in the solid state must be evaluated. Both choice of polymer and means of immobilizing the biocompound in the coating will influence performance.

When selecting an enzyme for incorporation into a coating, for example, there are specific characteristics that should be considered. Not only should the enzyme meet defined application parameters such as temperature, pH and type of substrate it will act upon, but also biochemical characteristics including stability, catalytic rate and substrate specificity.

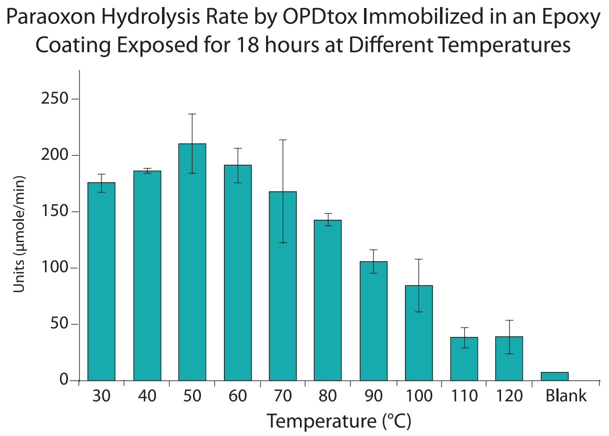
Proper assessment of application requirements and a detailed understanding of the functionalities that are available within an enzyme family is an essential consideration in enabling the development of a reactive coating.

Figure 5



Synergism in solution between ProteCoat and Verichem's N2000 biocide against B. atrophaeus. Solid circles indicate observed values, dotted line demonstrates expected result without synergism.

Figure 6



Thermal stability of OPDtox in epoxy coatings subjected to 18-hour exposure of temperature between 30-120° C.

One can choose from the immense diversity of function that can be found in nature or through the tools of genetic engineering create unique functionalities for specific purposes. For its DeGreez coating, Reactive Surfaces considered the extensive family of lipase enzymes that hydrolyze or synthesize triglycerides with different chemical specificities and physical characteristics. The critical parameters were judged to be: 1) broad specificity for chain length, 2) minimal regioselectivity, and 3) good thermostability. Three different lipases were chosen to evaluate these parameters.[23]

To create reactive or functional coatings, polymer, enzymes and reactants are blended to form a single macroscopic phase. Therefore, the next step in developing a functional coating is to prepare various formulations with different polymeric binders in order to determine the overall performance of the system. Three main methods have been reported for incorporating enzymes, peptides and other active bioadditives into a paint or coating:

- mixing into a final coating formulation;
- chemical or physical binding to the resin and then formulation of the coating; and
- chemical or physical binding to the surface of the film after the coating has been applied.

The simplest process involves blending the additive—usually in powder form—into a prepared coating. This method results in the additive being present throughout the thickness of the applied film. In general, waterborne coatings are preferred for this method because an aqueous medium is the natural environment for biomolecules. It is possible, however, to prepare enzymes and peptides that can be solubilized in organic media and still possess high reactivity.[6] As a result, these additives can be incorporated into solvent-based coatings as well.

Chemical modification involves directly binding the additive to the resin that serves as a binder for the coating. Since most of the bioengineered additives of interest are comprised of amino acids, it is possible to react the amine and carboxylic acid functionalities present in the biocompound backbone of the biomolecule with appropriate active sites on the resin. In this way, the enzyme, peptide or other bioadditive is tethered to the resin and enables the additive to be present throughout the entire film.

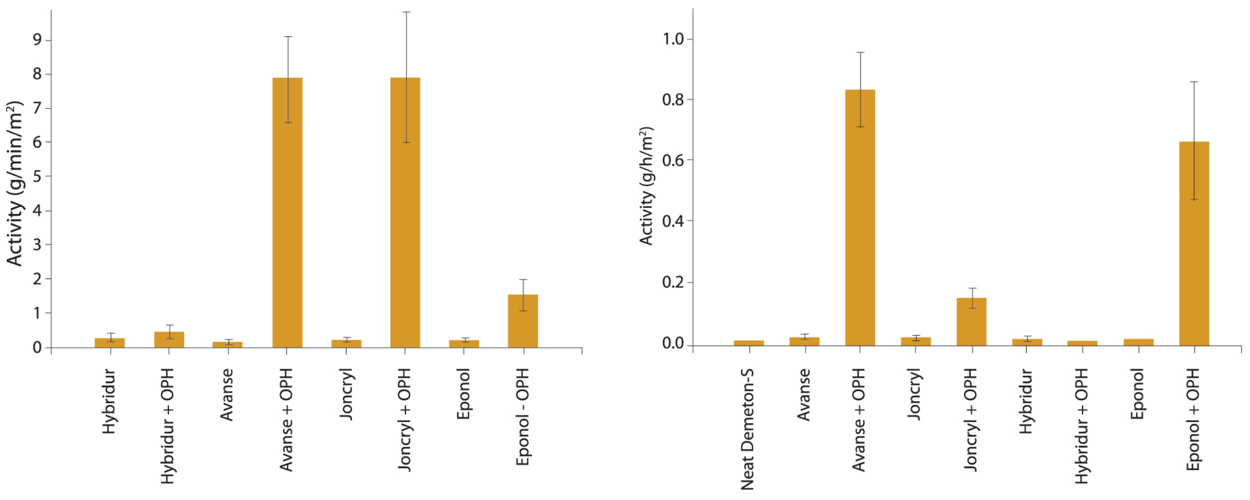
Similar chemistry can be accomplished after the paint or coating has been applied to the surface. This approach is the least attractive because it requires the applicator to carry out an additional step involving chemical reactants and presents practical complications. On the other hand, a smaller quantity of additive is required with this method as the bioactive compound is bound only to the coating surface.

There are several factors to consider when selecting a method for additive incorporation. Sensitivity of the bioactive material to the conditions required for incorporation is a critical factor. Interaction with other formulation components, including the resin, other additives (surfactants, fillers, etc.), initiators and solvent, for example, must be evaluated to determine effect on biomolecule activity and properties of the coating itself. Clearly, high through-put testing methodology should always be considered as the first approach.

Mode of bioadditive action is also important. Immobilization within the film may force conformations for enzymes or peptides that reduce their activity. The chemical binding sites chosen could modulate this effect. Porosity of the coating formulation can also be adjusted to allow the substrate to penetrate more easily into the film while also enabling increased biomolecule movement. These adjustments must be accomplished, however, without affecting the physical characteristics of the film.

The potential impact of such factors has been evaluated for enzymes embedded into coatings. It has been shown that the activity of enzymes incorporated into a solid matrix depends on the enzyme's conformation, orientation and physical state after incorporation.[24] The ability of reactants to diffuse to the catalytic site of the active enzymes has also been shown to play an important role.26 Property and performance optimization of the selected polymer type must match the sorption characteristics of the reactants.

Figure 7a & 7b



(a) Activity of the embedded OPDtox additive challenged against neat paraoxon monitored at 405 nm;
(b) Activity of the embedded OPDtox additive challenged against neat demeton-S monitored at 405 nm.

If the sorption profile of the reactant into the coating is not well understood, it is not possible to accurately characterize the latent functionality, activity and retention/optimization characteristics of the functional coating. In one example, it was determined that reactant sorption must be considered when selecting the most efficacious polymer type so that the decontamination activity of OPH enzymes matches the environmental conditions under which the coating will be expected to function. A study of the performance of the OPH enzyme in a number of different polymeric systems demonstrates the importance of careful coating binder selection.[25] Optimum functionality of the immobilized biocatalyst in this system can be achieved when the polymer closely matches the solubility parameters of the reactant, which ensures a reduction in diffusional constraints and enables saturation of the enzyme active site. Engineering functional coatings with latent, stable, extended film-life catalytic capabilities clearly requires an understanding of the many physical and chemical relationships that exist between the resin, the immobilized biocompound and the reagents to be acted upon under the expected environmental conditions (*see Figures 7 a & 7b*).

The impact of polymer composition can also clearly be seen in the case of embedded lipase enzymes. To screen for compatibility with polymer systems, Reactive Surfaces blended enzymes with solution phase polymers and then assessed the biocatalytic properties.[23] In general, lipase performed well in most of the tested resin systems, with the exception of the isocyanate system. Based on these results, the acrylic resin system (Avanse MV-100) was selected for formation of biocatalytic free films. Importantly, it was observed that the catalytic rate of hydrolysis increases with increasing surface area but is independent of bulk volume (*compare DeGreez lipase in Figure 8a to OPDtox hydrolase in Figure 8b*).

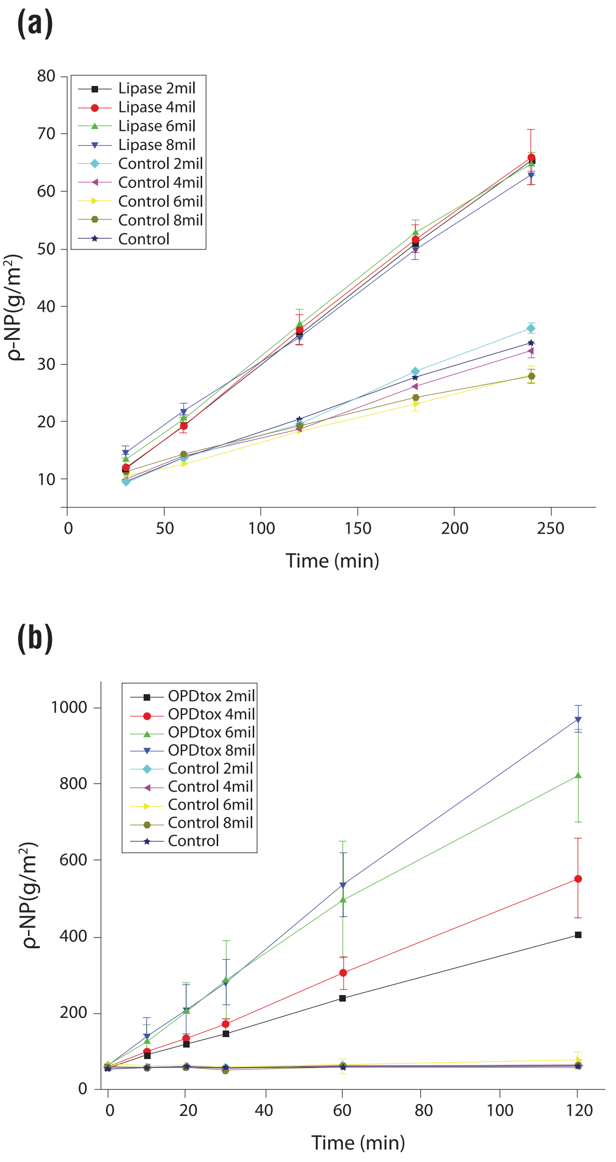
While performance is a critical issue, the potential impact of embedding the desired biocompound into a coating formulation on key coating characteristics is equally important. The modified paint or coating must continue to deliver desired physical properties such as gloss, hardness, adhesion and impact resistance. Evaluation of these parameters must also be completed in order to present a comprehensive assessment of coating performance.

In the case of lipase incorporation, Reactive Surfaces found that addition of the enzyme had no discernable effect on coating performance at levels of 3% and 14.3%, with all properties measured equaling the unmodified standard.23 With regard to chemical resistance testing, at the lower level of enzyme addition there was minimal effect on water and aqueous solution exposures with the only notable effects being observed with the 10% sodium hydroxide exposure and the red wine stain exposure. At high enzyme loading, greater film softening and varying degrees of blistering were observed upon exposure to water and aqueous acid, alkaline and chloride solutions when compared to the standard. Work is ongoing to improve the enzyme formulation in order to minimize the effects observed at higher enzyme loading levels.

Once an effective bioactive/polymer composition has been identified, the final step in the development of reactive coatings must include evaluation of activity under simulated application conditions. For example, to test the lipase modified coating, panels were coated with the lipase-containing formulation and heavily contaminated with a thick layer of vegetable oil. During a period of 72 hours, the coating cleared the surface of all oil.[23] DeGreez has also been shown to remain active in kitchen coatings after 100 and 200 scrub cycles using ASTM D3207.

These phases of biofunctional coating development can

Figures 8a & 8b



(a) DeGreez hydrolysis of p-nitrophenol acetate shows hydrolysis rate is not affected by bulk volume (film thickness); (b) OPDtox hydrolysis of paraoxon shows hydrolysis rate is affected by bulk volume

be and often are iterative. Ultimately, the integration of these various influences and development of the methodology to monitor and assess the critical variables is required for development of functional coating systems and for moving products from the development stage into a commercial product.

Scalability and economic impact are additional considerations. Blending is clearly the easiest and most cost effective method, but its physical impact must be evaluated. *Note: For some additives, it is also possible to apply the additive as a separate topcoat over the dried film. This choice is attractive for improving the functionality of existing surfaces without the need for complete recoating*.

Bioadditive stability is also an issue that must be addressed. It can be affected by formulation ingredients such as solvents, as well as by processing conditions and the means of immobilization. Once encapsulated within the film, the presence or absence of water, changes in pH, temperature and other aspects of the environment can also impact bioadditive performance.

Reactive Surfaces as well as other innovative companies and academic research groups have initiated intensive efforts to overcome these formulating challenges. In fact, the level of complexity can be considered an opportunity. With the ability to control and adjust so many different variables, it should be possible to optimize paint and coating formulations for maximum stability and activity while increasing the number of potentially different product variations. Ultimately this means that bioengineered additives can be carefully designed to meet the specific performance requirements of many different applications and provide high value-added formulations.

FROM DEVELOPMENT TO COMMERCIALIZATION

As mentioned above, biomolecules, particularly enzymes and peptides, have been widely used in various different industries for several decades. The technology for producing such bioactive compounds is well established and been shown to be cost effective on a large scale. In some cases, commercially available enzymes or peptides may be useful as additives without any need for further bioengineering efforts. In other cases, specially designed bioadditives will be required.

Reactive Surfaces has established partnerships with different academic research groups and loading biotechnology companies to ensure that production of proprietary bioadditives will be possible at scale in an economically viable manner. Access to existing manufacturing capacity will result in short commercialization times and increased speed to market. In addition, relationships with polymer chemistry experts and leading international paint manufacturers provide access to necessary formulation expertise.

OPDtox and DeGreez have already been launched and ProteCoat will follow once EPA registration has been com-

pleted. Research efforts continue to broaden these existing product lines and expand their scope of applicability into different markets. In addition, other active bioadditives are being investigated at Reactive Surfaces to enable development of unique product lines that present novel coating solutions (*to be discussed in the forthcoming third article in this series*).

PAINTING A BRIGHTER FUTURE

Reactive Surfaces views nature as a many hued palette of biomolecules with wide-ranging activities from which it can select novel functionalities to design unique additives for use in advanced coatings. Paint and coatings manufacturers can in turn use these bioengineered additives to create unprecedented value for their customers.

There is a growing market demand for in-film functional performance attained in an environmentally friendly manner. Biodegradable and nontoxic biofunctional additives meet these criteria. Add to these properties the ability to customize the functional additives to address specific market needs as well as unmet needs, to easily incorporate them using existing production processes, to produce them cost effectively and to apply the resulting paint and coating formulations in the usual manner, and the benefits become manifest.

The paint and coatings industry is driven by creating value that customers will recognize, that they will desire and for which they will be willing to pay a premium. Such innovation must reach the market fairly quickly and be formulated for easy use in order to provide sufficient opportunities for research, development and application. Bioengineered additives are undoubtedly one of the solutions to this challenge. The functional paints and coatings formulated with such biobased additives will create a major shift in value recognition. In the past, surfaces to be protected or beautified by a paint and coating held all of the value. In the future, that value will be shifted to the functional coating. ***CW***

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Coming next month in Part III

"Bioengineered Additives: Creating a Pipeline of Continuing Value with Bio-based Additives"

Abstract: Creating a pipeline cf added value using novel bioengineered additives is possible and is only limited by the imagination of coatings formulators. Stable, long-lasting, economic bio-based additives are now reaching the coatings market. But, new applications are being investigated to create a continuing flow of developmental bioadditives that will lead to further product introductions within the next few years and beyond.