

# Design of Experiments Helps Reduce Time to Remove Aerospace Coatings

Removal of coatings from military and commercial aircraft is becoming increasingly more difficult because coatings are being formulated to exhibit greater adhesion and impermeability, and environmental regulations are more strict. As a case in point, an aircraft manufacturer needed to remove a chromated primer prior to applying harness-attachment hardware during its aircraft manufacturing process. Dual action sanders were used in the past for this process, but recent EPA regulations have limited the release of airborne chromates, thus making this method prohibitive. As a result, Aerochem, Inc., a supplier of coating removers based in Oklahoma City, Oklahoma, was asked to develop a chemical paint remover that would remove the coating in less than 2 hours. Existing formulations on the market took as much as 8 hours to remove the coating, which would be unacceptable to the manufacturing schedule. Aerochem used the design of mixtures (DOM) method to optimize the formulation of the coating remover. They accomplished this task while staying within the range of mixtures that had already been approved on the material safety data sheet (MSDS). The optimized formula generally removes the coating in only 30-45 minutes.

A diverse range of coatings are used in the aerospace industry. One common system consists of a top coat of polyurethane and an epoxy primer. Coatings on military planes are typically removed every few years for refinishing, at which time the aircraft structure is checked for corrosion from operating at high stress levels in sometimes corrosive environments. Paint removers used to remove military coatings must be able to remove all elements of a particular coating system. They are designed to migrate through each layer of the coating system and remove it either by causing the coating to swell and delaminate or by dissolving the coating through a process known as cohesive failure. Coating removers must also avoid damaging the metal and composite substrates. They are typically tested on a variety of metals used in aerospace structural applications such as 2024 and 7075 bare aluminum, cadmium plated steel, titanium, 1020 bare steel, and magnesium. Another important concern is avoiding hydrogen embrittlement of high strength steel used in aircraft landing gear components.

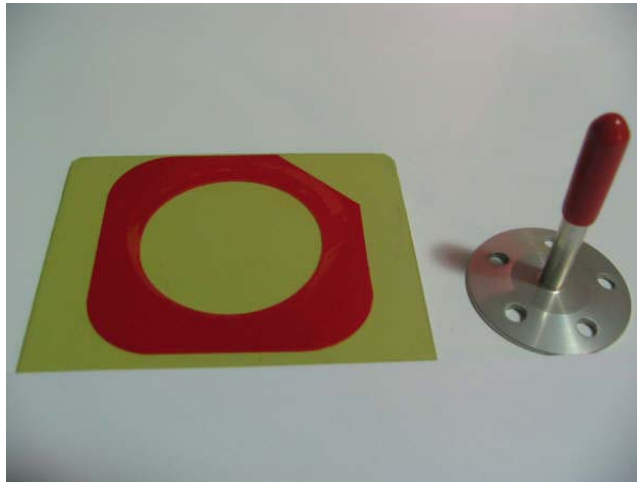
## **Challenges of aerospace coating removal**

Regulations have become stricter on the use of chemicals that have proven most effective at removing coatings. In particular, the use of methylene chloride, the previous standard for coating removal, has been virtually eliminated by EPA's Aerospace NESHAP (National Emissions Standards for Hazardous Air Pollutants) Regulation promulgated in 1996. As a result, suppliers of coating removers have had to identify new materials that are capable of removing today's even-tougher coatings while avoiding aircraft corrosion and hydrogen embrittlement problems.

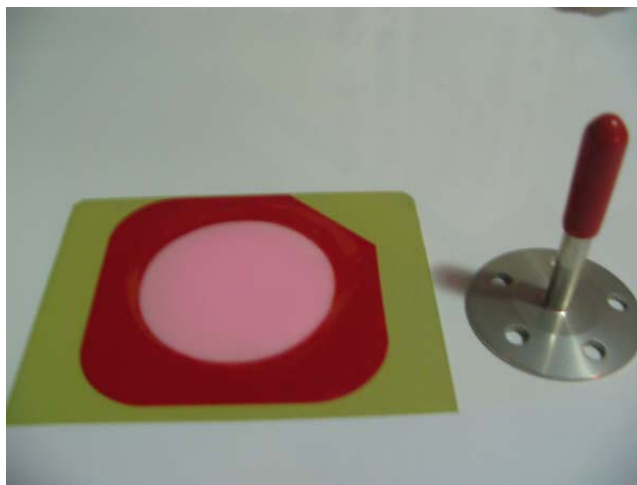
Coating removers typically consist of five or six different components. Several components called activators are designed to remove the various layers of the coatings system and the proportion of these materials is typically varied to improve performance on specific coating systems. Other components may be designed to stabilize the formulation, extend shelf life, and prevent corrosion and hydrogen embrittlement.

Normally, the determination of the precise formula for coating removers is largely a matter of trial and error. Chemists use experience and instinct to mix up batches that they think might be effective in removing a particular type of coating. These formulations are tested by applying them to coating panels and noting whether they are able to remove the coating and how long it takes. The coating removers are also tested against metals to evaluate whether they cause corrosion or hydrogen embrittlement. The formulation that removes the coating system in the least amount of time without causing other problems is used in the application.

The weakness of this approach is that the tests are expensive to run. Also, there is typically only enough time to test a relatively small number out of the huge number of possible formulations. So it may be either expensive or impossible to find a formulation that meets the requirements of the application. In any case, optimization is impossible using this method of formulating a coating remover. A more scientific approach is required to provide a product with the best results at an affordable price.



**Maskant applied and ready for depaint process**



**Plane naked paint remover applied to the masked off area.**



**Plane naked paint remover working after only 30 minutes.**



**Area depainted and ready in under 45 minutes.**

### **Moving to a scientific product development process**

For these reasons, Aerochem turned to DOE and DOM methods to improve coating remover performance. DOE/DOM drastically reduces the number of runs required to determine the optimal value of each factor by varying the values of all factors in parallel. This approach determines not just the main effects of each factor but also the interactions between the factors. DOE/DOM makes it possible to identify the optimal values for all factors in combination. It also requires far fewer experimental iterations than the traditional one-factor-at-a-time approach.

With the use of DOE/DOM, Aerochem was able to deliver a result that exceeded the customer's expectations. Chris Hensley of Aerochem asked the manufacturer for samples of panels to use in developing a new formulation. The MSDS for the original formulation specified a range of concentrations for the three key active ingredients. The proportion of ingredient A was varied between 0 and 5%, ingredient B between 0 and 5%, and ingredient C between 2 and 7%.

## **D-optimal design used to optimize formulation**

Hensley used Design-Expert® software from Stat-Ease, Inc., Minneapolis, Minnesota, to design an experiment to optimize the formulation within the limits defined by the MSDS. He originally selected the software because it is designed for use by subject matter experts who are not necessarily experts in statistical methods. The software walks users through the process of designing and running the experiment and evaluating the results. Hensley selected the D-optimal design because it provides the minimal number of blends ideally formulated to fit a given predictive model. Hensley selected a quadratic model which includes the non-linear blending terms for detection of component combinations that may be significantly antagonistic (detrimental) or synergistic (beneficial).

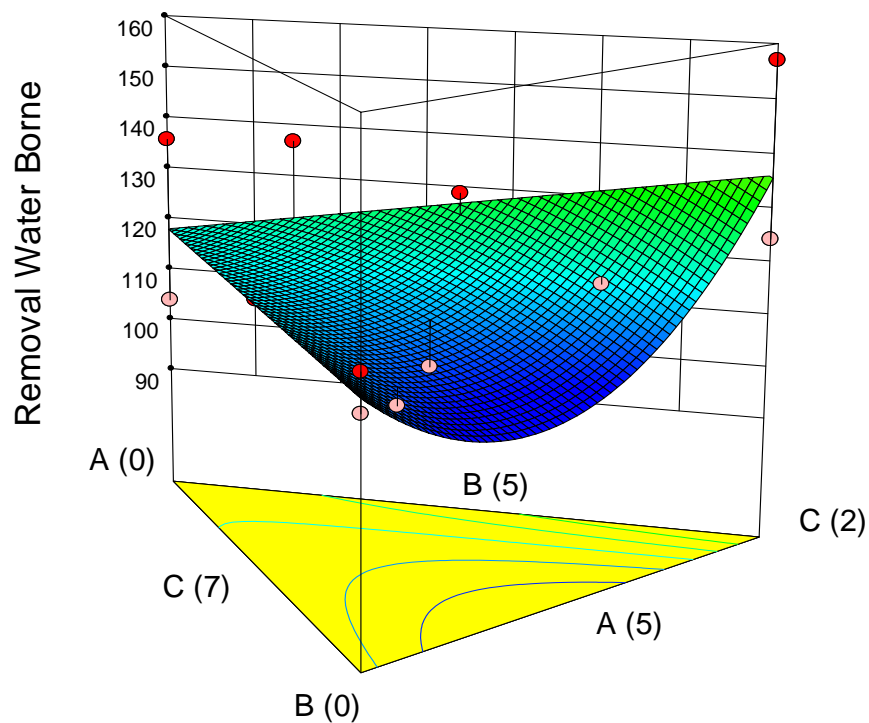
Design-Expert software specified an experiment with 17 runs. All three components were varied simultaneously so that their interactions with each other would be captured by the experiment. Hensley's team created a base batch consisting of the 88% of the formulation that was constant for each batch and then separately mixed the 12% of the formulation that accounted for the precise proportions of active ingredients selected by Design-Expert for each run. Technicians measured the time that each of the 17 formulations took to remove the coating. Then they entered the results into Design-Expert and the software performed statistical analyses. The normal plot of residuals showed a high level of correlation between each of the data points, indicating that the results were internally consistent. The Box-Cox transformation of dependent variables showed that the variances in the experimental conditions were homogenous and uncorrelated with the means so a power transformation was not needed to stabilize the variances.

Design-Expert software then predicted the optimal formulation, within the constraints of the MSDS, consisting of 5% of ingredient A, 1.93% of ingredient B, and 5.07 of ingredient C. The DOE software predicted that this formulation would remove the coating in 75 minutes. The Aerochem team produced this formulation and it actually removed the coating in only 45 minutes. These results were reproduced by the customer and resulted in the Aerochem formulation being the first product approved for use on this application. Aerochem is creating a package that includes the new coating remover, the maskant material with a hole that exposes the area where the coating is to be removed, and a cover that seals off the area after the coating remover has been applied. The aircraft manufacturer is now working towards implementation of this new process.. Other major manufacturers have also expressed strong interest. By using DOE/DOM in place of traditional trial and error methods, Aerochem was able to help resolve a very urgent issue for the Aerospace Industry and is enabling the aircraft manufacture to continue operations safely without adversely affecting production times.

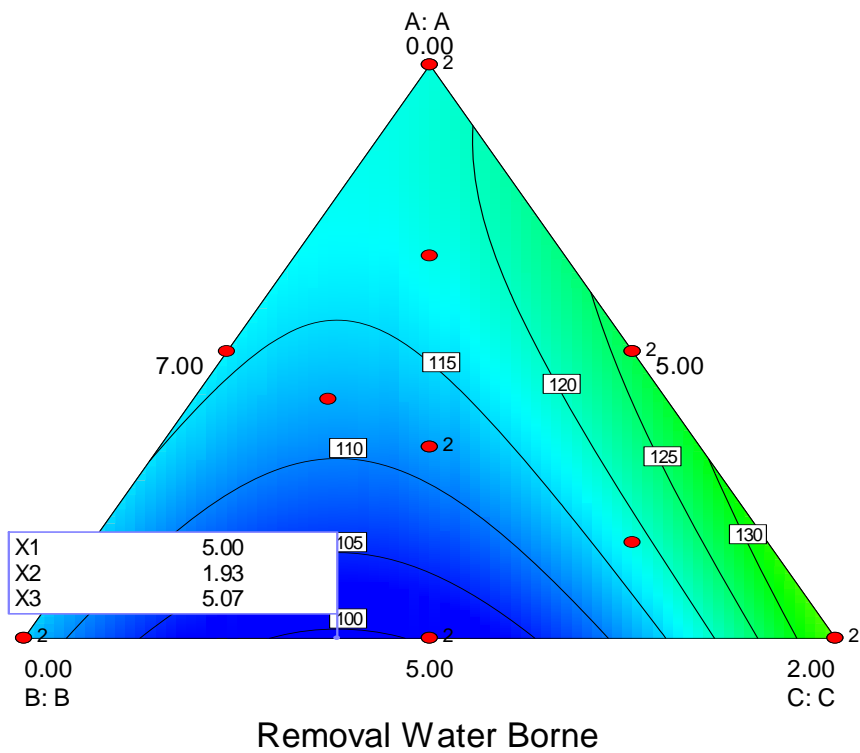
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**3D surface pictures predicted response as a function of formulation**



**Ternary contour plot shows the optimal formulation**