

**NEW DEVELOPMENTS IN STARCH-BASED ABRASIVE MEDIA  
AN OVERVIEW OF RESEARCH AND DEVELOPMENT ACTIVITIES  
AT ARCHER DANIELS MIDLAND**

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**ABSTRACT**

Research and development efforts in support of the aerospace industry have been ongoing at ADM/Ogilvie since the introduction of **ENVIROStrip<sup>®</sup> Starch Media** in 1990. The objective of ADM's new media development program is to develop more efficient media types for applications under different operating conditions (e.g. extremely high or low humidity), whilst preserving the unique mechanical properties of Envirostrip. ADM is currently considering several new 100% organic media products. Some of these new media products are designed to replace Type V plastic media and are engineered as true "drop-in" replacements in existing plastic media blast (PMB) facilities. This presentation will outline the methods used to evaluate blast media candidates, as well as present the preliminary performance results of promising new media products in comparison to Type V plastic media.

**INTRODUCTION**

**R&D BACKGROUND**

ADM/Ogilvie developed Envirostrip wheat starch media in the late 1980's and launched the product commercially in 1990. The focus of the product development was on finding a suitable abrasive that could provide low mechanical effects combined with reasonable stripping efficiency. Several carbohydrate sources and a variety of starches - including corn, potato and pea - were evaluated alongside wheat starch. Once a suitable manufacturing process was established with the preferred product made from wheat starch, Ogilvie Mills at the time applied for key patents to protect its technology. Patents were granted worldwide for the use of starch abrasives (e.g. US Patent No. 5,066,335), the manufacture of starch-based abrasives (e.g. US Patent No. 5,367,068), and the nature of the starch abrasive product itself (e.g. US Patent No. 5,360,903).

Since 1993, ADM has concentrated primarily on optimizing the process application technology. By establishing its own test center, ADM has been able to support various aerospace organizations evaluating Envirostrip. As well, ADM has provided a test bed for improving dry stripping equipment technology for starch media, and an initial site for automation development. During this time, a continuous process improvement program has ensured that the manufacturing process and quality control have improved without changing the known properties of Envirostrip.

The efforts to develop new organic media types at ADM have been ongoing since 1991. Up until 1996 the main push was to support commercial applications and prove the merits of the original Envirostrip technology. Now that starch media's commercial success and use have expanded to several aerospace applications, ADM has accelerated the development of next generation organic abrasive medias. During the last several years, a considerable number of experimental candidates have been produced and evaluated at ADM's test facilities. One particular goal has been to develop a starch abrasive that approaches the productivity of Type V PMB while providing the low mechanical effects possible with starch-based abrasives.

### **GOAL IS TO MEET INDUSTRY REQUIREMENTS**

The aerospace industry requires different starch media types to suit the wide variety of applications today. One product cannot be expected to have all the properties necessary to meet all situations. This need for additional organic media types is driven not only by different application requirements, but by operational and equipment restrictions as well. Working closely with its customers, ADM is confident that it can develop new starch-based abrasive types to satisfy a broader range of aerospace applications.

### **NEW PRODUCT DEVELOPMENT PROGRAM**

The objectives of ADM's product development program are:

- a) To develop new media types for different aerospace applications while preserving Envirostrip's unique mechanical qualities;
- b) To develop new starch-based media types that are 100% organic, non toxic and biodegradable.

There are several criteria that a new candidate media must meet before large scale testing is initiated at ADM. When compared to Envirostrip, it must match or exceed overall performance while offering a significant advantage in one or more of the following characteristics:

1. Mechanical effects
2. Production rates (strip rates)
3. Consumption rates
4. Moisture sensitivity
5. Material handling characteristics

The objective of this paper is to outline the approach, methodology and preliminary results of some promising media candidate types.

## **DISCUSSION**

### **EVALUATION CRITERIA**

#### **1. Mechanical Effects**

The primary reason Envirostrip has been widely accepted by aircraft manufacturers is the low mechanical effects associated with the process. The concern with any paint removal process is whether the fatigue properties of aerospace materials are affected by the stripping process. Past studies have shown that significant reductions in fatigue life and increases in fatigue crack growth rate can occur - depending on the substrate thickness - if the dry blasting media used is too aggressive. Consequently, ADM's goal is to develop new products for the aerospace industry which deliver mechanical properties that are similar to Envirostrip.

Since ADM is investigating a large number of experimental media types, initial testing to select promising prototypes is being limited to Aero Almen tests and surface roughness ( $R_a$ ) measurements obtained on alclad surfaces. For quick, but effective residual stress measurement, the Aero Almen test is still considered the benchmark for engineering purposes. Aero Almen strips have been blasted by the USAF and other aerospace organizations with a variety of different mechanical processes over the years. Although studies have not conclusively correlated Almen arc heights to changes in fatigue life, Aero Almen tests are still considered indicative of the residual stress levels imparted on thin aluminum substrates.

#### **2. Production Rates**

A credible coating removal study will attempt to simulate as closely as possible the process stripping conditions, and hence determine the potential effects and productivity of the coating removal process in question. With dry stripping technology there are two possible application methods: manual and automated. Since the dynamics of the two application methods can be quite different, it is preferable to evaluate processes with both methods where possible. ADM uses a round double venturi nozzle in manual test and a flat nozzle in automated tests. At this time, initial manual tests have been performed and automated evaluations are ongoing. Note that productivity results are expected to show the typical 3:1 increase in strip rate with automated application (with flat nozzles) versus manual stripping.

#### **3. Consumption Rates**

The economics of dry stripping are driven first by strip rates, and then by product consumption rates. Minimizing blast media consumption or prolonging product life can provide significant savings to users. Consequently, any improvement in this aspect is always welcomed. Consumption for both five blast cycles and ten blast cycles are obtained for candidate products. Consumption rate is defined as the original media sample weight less the usable media that remains after a given number of blast cycles. The difference is the amount of media lost or consumed which can then be

divided by the number of cycles used to give an average percent (%) consumption figure per cycle or use.

#### **4. Moisture Sensitivity.**

One of the known characteristics of starch-based media is moisture sensitivity. This manifests itself when these products come in contact with water within blast equipment. This can happen when condensation forms within pressure pots due to rapid depressurization, or when inadequately dry compressed air brings condensate into the pressure vessel. Both situations lead to operational problems that can interrupt dry stripping work. Properly designed equipment and installations manage this aspect of Envirostrip Starch Media very well. However, the goal of next generation starch abrasives is to modify this property so that starch abrasives can be used in any type of light abrasive blast equipment.

#### **5. Material Handling Characteristics**

The manner in which dry bulk solids (e.g. abrasive media) will flow in a material handling system can be predicted to some degree by determining the angles of repose and the angle of slippage of the dry solid. These simple and quick tests help to indicate whether conventional plastic media dry stripping equipment design (e.g. pneumatic systems, storage hoppers, pressure pots) can adequately handle a given type of dry abrasive media.

An accepted measurement technique consists of using a funnel to make a cone shaped pile of media and measuring the angle of repose with a protractor. The angle of repose is defined as the angle between the incline of the media pile and the horizontal plane. To determine the angle of slippage, once the pile of media is poured onto a flat plate and the angle of repose recorded, the plate is gently lifted on one side until the pile starts to break. The angle of slippage is then calculated by taking the slippage angle, which is the angle between the base plate and the horizontal, and adding this to the angle of repose.

An angle of slippage above 60° for starch abrasives is generally indicative of potential flowability problems in standard plastic media blast equipment. In this case, bridging of product or rat holing can be encountered when emptying silos, storage hoppers, and pressure pots. More rigorous testing is then required to determine the minimum critical bridging diameter of silo/storage hopper outlets and the minimum slope angle for proper hopper design.

## **STARCH MEDIA TECHNOLOGY BACKGROUND**

### **STARCH MEDIA DRY STRIPPING**

Over the years, the merits of Envirostrip and starch-based abrasive media have been acknowledged by many aerospace organizations. ADM's dry stripping technology has been in production use for 7 years and boasts an impressive list of successful applications.

The reason for the trend to starch-based abrasives is simple. Starch-based products offer a unique advantage over other abrasive products when dry stripping aerospace materials. They provide reasonable stripping efficiency while imparting low mechanical effects to aluminum and composite structures. These low mechanical effects are attributable to the non-elastic behavior of starch polymer/water structures found within starch abrasives. When starch abrasives impact a surface, they absorb significant amounts of kinetic energy internally, rather than transferring that energy to the surface being blasted. The water, both free and tightly bound within the starch structure, provides this energy absorbing ability. This phenomenon explains the low mechanical effects of starch media dry stripping on aerospace materials.

Plastic media abrasives on the other hand have a totally different chemistry and do not benefit from the plasticizing effects of water. Thus, abrasives manufactured with synthetic polymers cannot reproduce the mechanical properties of starch abrasive materials, regardless of the plastic media blasting parameters used.

### **MORE TO STARCH TECHNOLOGY THAN MEETS THE EYE**

Starch technology can be used to create a number of variants to Envirostrip Starch Media. While Envirostrip in its current form is manufactured from wheat starch using extrusion technology, the following variables can be introduced:

- different raw starch sources or combinations (e.g. wheat, corn, potato, tapioca, rice, etc.)
- different genetic varieties of starch (thereby varying molecular structure and properties)
- modified extrusion process conditions (extrusion temperature, residence time, and energy input)
- chemical modifications which can
  - substitute chemical groups onto starch polymers
  - chemically cross-link starch polymers
  - hydrolyze starch polymer chains

Envirostrip in its current form, and any starch abrasive, is most efficiently manufactured in the following way (ref. ADM US Patent No. 5,367,068). Raw starch (wheat, corn etc. or a genetic variety) is fed to an extruder along with water. The extruder gradually heats the starch/water mixture until the starch polymers begin to solubilize, a process referred to as gelatinization. This cooked starch mixture is further heated as it moves along the extruder barrel, although by now it is very viscous. Upon leaving the extruder, the starch mixture is formed into strands that are pelletized and then cooled. These pellets harden with time and are then ground into the appropriate product mesh size.

A number of promising starch abrasive prototypes have been manufactured over the last several years. ADM plans to develop more prototypes through its R&D efforts. However, two candidate products have shown much promise and will be referred to from here on as Envirostrip<sub>XL5</sub> and Envirostrip<sub>XL7</sub>. These experimental abrasives were extruded and processed in a special manner and are not made from a wheat starch base. What follows is an example of the evaluations and a sample of the results obtained with these two prototype products.

## **EXPERIMENTAL PROCEDURES & PARAMETERS**

### **TEST EQUIPMENT**

Preliminary screening of all new media types at ADM is done using a modified Pauli Systems PRAM 31 hand cabinet. The cabinet has a computer controlled x-y table to conduct precise automated tests and other features to facilitate the rapid performance characterization of experimental abrasives (see Exhibit 1). Each media prototype is tested initially in small 30-lb. batches in the hand cabinet. Those products that show the most promise are then evaluated on a larger scale in 6000-lb. quantities at the ADM test facility.

The results presented in this paper were based on testing conducted in a hand cabinet. The blast pressure was continuously monitored at the pressure pot by a digital pressure gauge. The nozzle pressure was verified at the beginning of every blast cycle by two different digital needle gauges. Media flow was accurately controlled using a Pauli Systems Accu-Flow Valve, which is computer controlled and for this work was adjusted to a setting of 90 on the digital display for all tests. The time to blast and corresponding flow rate were verified on every blast cycle.

### **COATED TEST PANELS**

The coated test panels used in the evaluation program were voluntarily supplied to ADM by various aircraft manufacturers. In order to assess to some degree how each media prototype responds to different types of coating systems, a minimum of four coating systems were studied. Each coating system was applied to 0.032-inch thick clad aluminum.

The strippability of coating systems can be affected by a number of variables, including the type of coating, the coating manufacturer, the application process, and, perhaps most importantly, the aging process. Other factors that influence dry stripping efficiency are coating thickness, hardness and adhesion properties. It should be noted that not all panels submitted passed minimum adhesion requirements and those that failed were dropped from testing. Once commercial quantities are available, ADM will supply sample quantities to selected organizations for preliminary field evaluations.

**Table 1.****Summary of Coating Properties of Painted Panels Tested.**

	COATED TEST PANELS			
	SERIES A	SERIES B	SERIES C	SERIES D
COATING SYSTEM	COMMERCIAL POLY-URETHANE TOPCOAT, POLYAMIDE EPOXY PRIMER	COMMERCIAL POLY-URETHANE TOPCOAT, POLYAMIDE EPOXY PRIMER	MIL-SPEC POLY-URETHANE TOPCOAT, POLYAMIDE EPOXY PRIMER	COMMERCIAL POLY-URETHANE TOPCOAT, POLYAMIDE EPOXY PRIMER
COATING THICKNESS	5.0 - 5.5	5.2 - 5.7	2.5 - 3.0	4.0 - 4.5
COATING ADHESION (DRY)	6B	6B	6B	6B
COATING HARDNESS	5H	4H	6H	5H

These panels prepared by aircraft manufacturers met or exceeded industry standards for paint hardness and adhesion properties.

### **BLASTING PARAMETERS USED**

#### **Envirostrip Series Parameters**

Nozzle type            $\frac{3}{8}$ -inch Double Venturi  
 Nozzle pressure       $30 \pm 1$  psi  
 Media flow rate      8 - 9 lb/minute  
 Nozzle angle         40 - 60 degrees  
 Nozzle distance      6 - 7 inches

#### **Type V Acrylic PMB Parameters**

Nozzle type            $\frac{3}{8}$ -inch Double Venturi  
 Nozzle pressure       $25 \pm 1$  psi  
 Media flow rate      7 - 8 lb/minute  
 Nozzle angle         50 - 70 degrees  
 Nozzle distance       $10 \pm 1$  inches

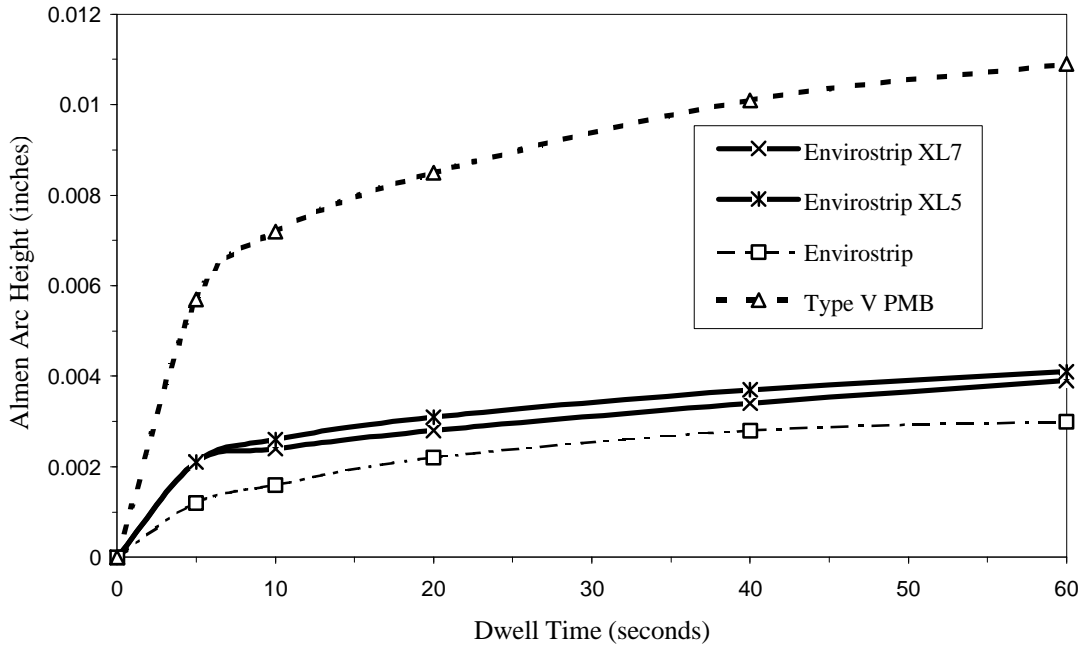
### **DISCUSSION OF RESULTS**

#### **ALMEN ARC HEIGHT MEASUREMENTS**

Using the parameters listed above and the same procedures as when determining comparative strip rates, four Aero Almen strips (bare 2024 T-3 aluminum, 0.032 inch thick) were blasted with each abrasive product. The Almen specimens were blasted initially for 5 seconds, removed and measured using an Electronics Inc. Almen gauge instrument. The procedure was repeated to give total blast dwell times of 10, 20, 40, and 60 seconds. The cumulative residual stress imparted by Envirostrip<sub>XL5</sub> and Envirostrip<sub>XL7</sub> are compared to Type V Acrylic PMB as shown in Figure 1. Typical Envirostrip Starch Media arc heights are included as reference. Note that the results are based on an average of four Almen strips at each data point.

These Almen arc height results suggest that next generation starch abrasives can provide surface effects comparable to Envirostrip Starch Media.

**Figure 1.** Almen Arc Height Saturation Curves for Envirostrip, Envirostrip<sub>XL5</sub>, and Envirostrip<sub>XL7</sub> versus Type V PMB



### SURFACE ROUGHNESS

Surface roughness measurements were performed on the stripped areas of the clad aluminum (0.032-inch, 2024 T-3) panels using a Mitutoyo MST 301 profilometer. Panels marked series A, B and C were stripped to the bare metal and the surface roughness was measured on the exposed clad layer for each abrasive product. For panel series D, selective stripping was performed and the surface roughness of the remaining primer was measured for each abrasive product. Note that six scans were performed on each area using a cut length of 0.030-inch x 5. The average  $R_a$  (roughness average, micro in.) values obtained are presented in Table 3.

**Table 3. Summary of Surface Roughness ( $R_a$ ) obtained on stripped panels tested.**

	<b>SURFACE ROUGHNESS <math>R_a</math> ( <math>\mu</math>INCHES)</b>			
<b>COATED PANEL</b>	<b>SERIES A</b>	<b>SERIES B</b>	<b>SERIES C</b>	<b>SERIES D</b>
<b>ENVIROSTRIP</b>	124	105	106	58
<b>ENVIROSTRIP<sub>XL5</sub></b>	137	129	119	60
<b>ENVIROSTRIP<sub>XL7</sub></b>	132	128	122	69
<b>TYPE V PMB</b>	241	222	181	76

**STRIP RATES**

To conduct strip rate tests, and provide an apples to apples comparison, all three media types were conditioned for several cycles in order to have the same relative mesh size distribution. The tests were performed manually using the same process parameters as with the consumption rate tests. A small rod was attached to the nozzle to serve as a guide for maintaining the correct distance. The nozzle was held at an angle of 40°- 60° in the case of starch media prototypes, and 50°- 70° for Type V PMB. Table 4 presents a summary of the strip rate results.

**Table 4. Summary of Strip Rate Results obtained on four panel types tested.**

	<b>STRIP RATE ( FT<sup>2</sup>/MINUTE)</b>			
<b>COATED PANEL</b>	<b>SERIES A</b>	<b>SERIES B</b>	<b>SERIES C</b>	<b>SERIES D<sup>†</sup></b>
<b>ENVIROSTRIP<sub>XL5</sub></b>	0.44	0.55	0.36	0.46
<b>ENVIROSTRIP<sub>XL7</sub></b>	0.43	0.44	0.40	0.45
<b>TYPE V PMB</b>	0.50	0.48	0.41	0.50

<sup>†</sup> - Selective stripping was performed leaving as much primer intact as possible. Considerably less primer was left intact with Type V versus the Envirostrip Series products.

## **DETERMINATION OF CONSUMPTION/BREAKDOWN RATES**

In the case of the starch-based abrasives, the blast nozzle was fixed to a nozzle holder to maintain a constant 45° angle and a distance of 6-7 inches from the target surface. The target surface was a 0.250-inch thick plate made from 7075 T-6 aluminum. 30-lb.samples of each media type were cycled 5 and 10 times. These tests were repeated by a second person (blind test) following the same procedures as established in the first set of tests. The breakdown rates for Envirostrip<sub>XL5</sub> and Envirostrip<sub>XL7</sub> prototypes were found to be lower than Envirostrip suggesting less product consumption with these new prototype products. Additional large scale testing will be performed to confirm initial findings.

## **MOISTURE SENSITIVITY**

The Envirostrip<sub>XL5</sub> and Envirostrip<sub>XL7</sub> prototypes were found to have very different behavior in the presence of water when compared to other starch abrasives. Typically when starch-based media comes in contact with water, considerable absorption and particle swelling occurs. When immersed in water, these prototype products do not behave the same as standard Envirostrip in that they do not swell or form a gel nor do they form a single mass upon drying. When left to dry, Envirostrip<sub>XL5</sub> and Envirostrip<sub>XL7</sub> media become particulate again. This unique characteristic illustrates how different these experimental media are from standard Envirostrip. Although the water sensitivity of standard Envirostrip can be managed with properly designed equipment and facilities, in more marginal equipment facilities condensation within pressure pots and air supply lines may result in operational problems (see Exhibit 2).

## **ANGLE OF REPOSE AND ANGLE OF SLIPPAGE RESULTS**

In order to assess each prototype starch abrasive's behavior in standard plastic media blast equipment, a representative production mix is taken and the angles of repose and slippage determined. As discussed earlier, if the angles of repose and slippage are both below 60°, this provides a reliable prediction of good product flowability in any type of PMB equipment. Table 5 presents the angle of repose and slippage data recorded in each case. Here we see that the Envirostrip<sub>XL5</sub> and Envirostrip<sub>XL7</sub> prototypes have angles of repose and slippage that are very similar to Type V PMB, indicating flowability characteristics similar to PMB (see Exhibits 3 and 4).

Note that Envirostrip Starch Media has an angle of repose greater than 60°. Experience has shown that specially designed blast equipment is preferred and highly recommended for efficient use of Envirostrip Starch Media.

**Table 5. Summary of Angle of Repose and Angle of Slippage for Envirostrip<sub>XL5</sub>, Envirostrip<sub>XL7</sub>, and Type V PMB.**

<b>ABRASIVE PRODUCT</b>	<b>ANGLE OF REPOSE</b>	<b>ANGLE OF SLIPPAGE</b>
<b>ENVIROSTRIP<sub>XL5</sub></b>	38° ± 2°	53° ± 2°
<b>ENVIROSTRIP<sub>XL7</sub></b>	38° ± 2°	53° ± 2°
<b>TYPE V PMB</b>	35° ± 2°	50° ± 2°

**FLUORESCENT CHARACTERISTICS**

Envirostrip<sub>XL5</sub> and Envirostrip<sub>XL7</sub> exhibit fluorescence when exposed to ultraviolet light. An additional benefit, fluorescence will facilitate post stripping inspections for possible media ingress. This fluorescent characteristic may also alleviate concerns about the possibility of cracks filling with blast media. The fluorescent characteristic of the prototype products are compared to Type V plastic (see Exhibits 5, 6, 7 and 8).

**CONCLUSION**

ADM’s research and development efforts over the last several years will spawn a new generation of dry stripping abrasives. The prototype products currently being explored have the potential to have a significant impact on aerospace dry stripping applications.

The Envirostrip<sub>XL5</sub> and Envirostrip<sub>XL7</sub> prototypes are showing excellent potential. They appear to provide the same low mechanical effects as Envirostrip in terms of Almen Arc height and surface roughness measurements. These products also seem to provide comparable strip rate performance when compared to Type V Acrylic PMB. Further large-scale testing of Envirostrip<sub>XL5</sub> and Envirostrip<sub>XL7</sub> will confirm that product consumption is better than Envirostrip Starch Media. Finally, and most importantly for certain applications, these new starch abrasive prototypes display improved moisture resistance and flowability, allowing them to be used in any type of plastic media or light abrasive blast equipment.

ADM recognizes the appreciable investment borne by aerospace organizations when qualifying new process technology. Thus rigorous testing and evaluations are performed to ensure that products being considered for commercial launch have sufficient benefits to merit the industry’s evaluation. By reproducing the mechanical effects of the widely approved Envirostrip, evaluation efforts of ADM’s new starch abrasives by industry should be considerably reduced.



EXHIBIT 1, AUTOMATED BLAST CABINET

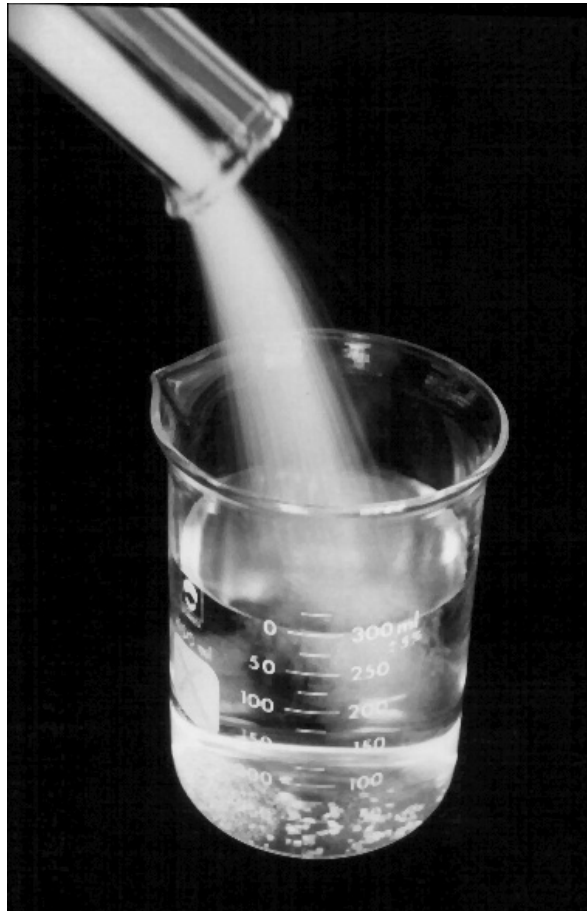


EXHIBIT 2, XL media does not gel in water

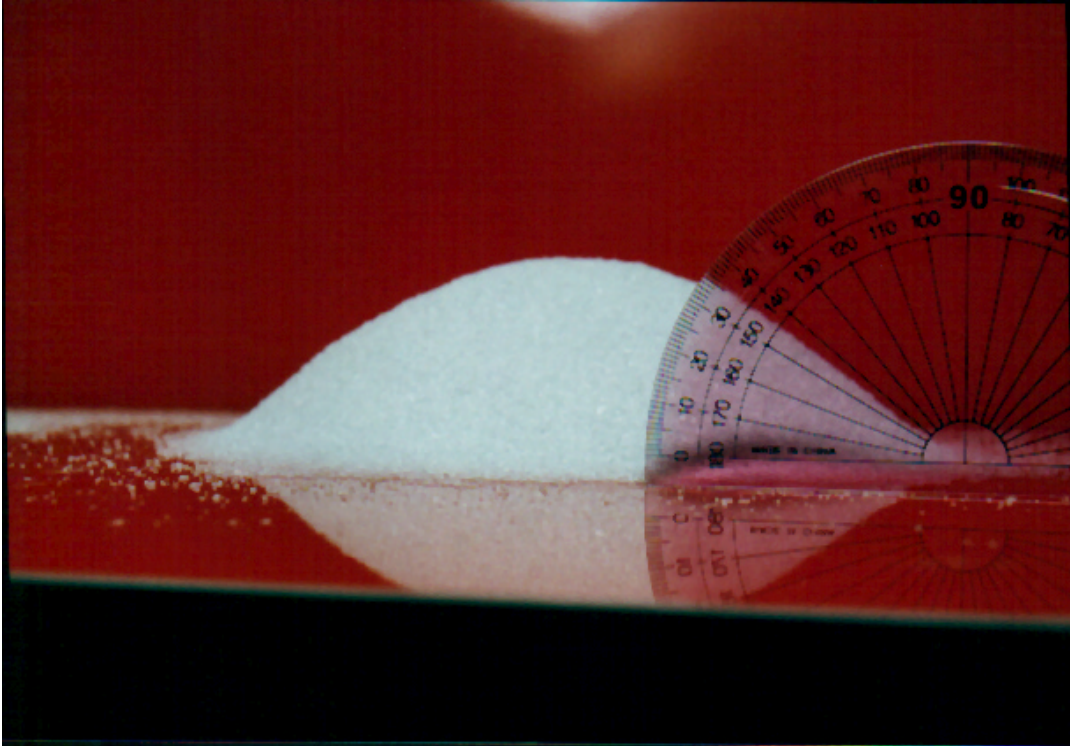


EXHIBIT 3, Type V angle of repose,  $35^\circ$

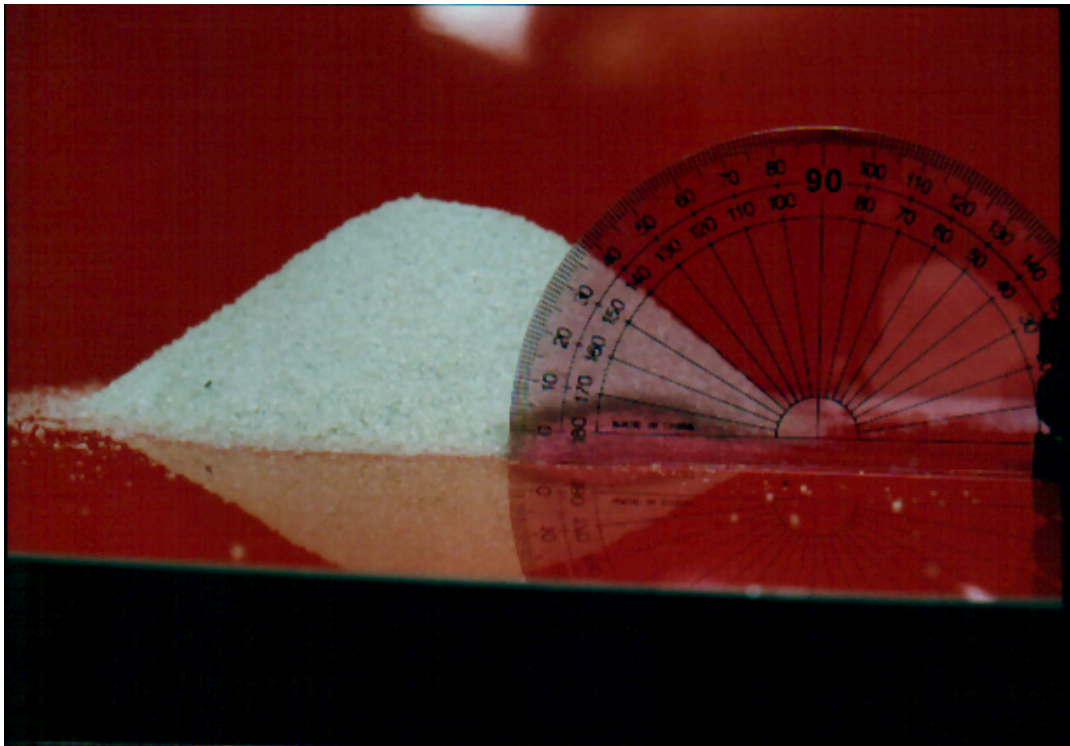


EXHIBIT 4, XL media angle of repose,  $38^\circ$



EXHIBIT 5, ultraviolet light response of XL series product (left) compared to type V plastic (right)

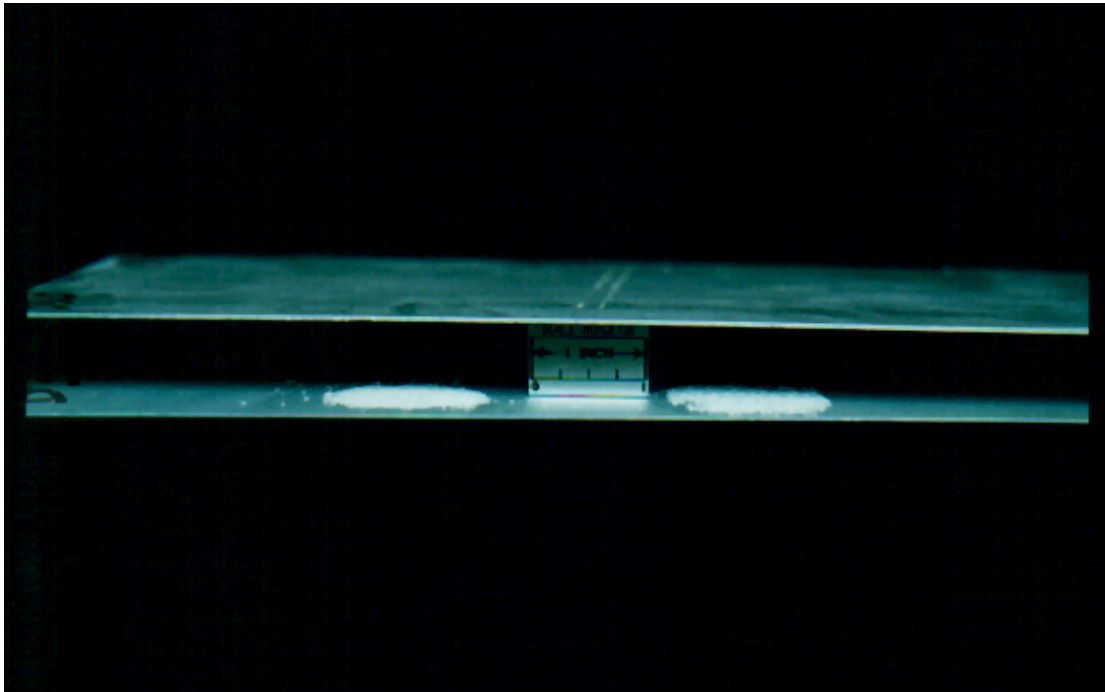


EXHIBIT 6, simulated media ingress situation, XL on left-hand, type V on right-hand

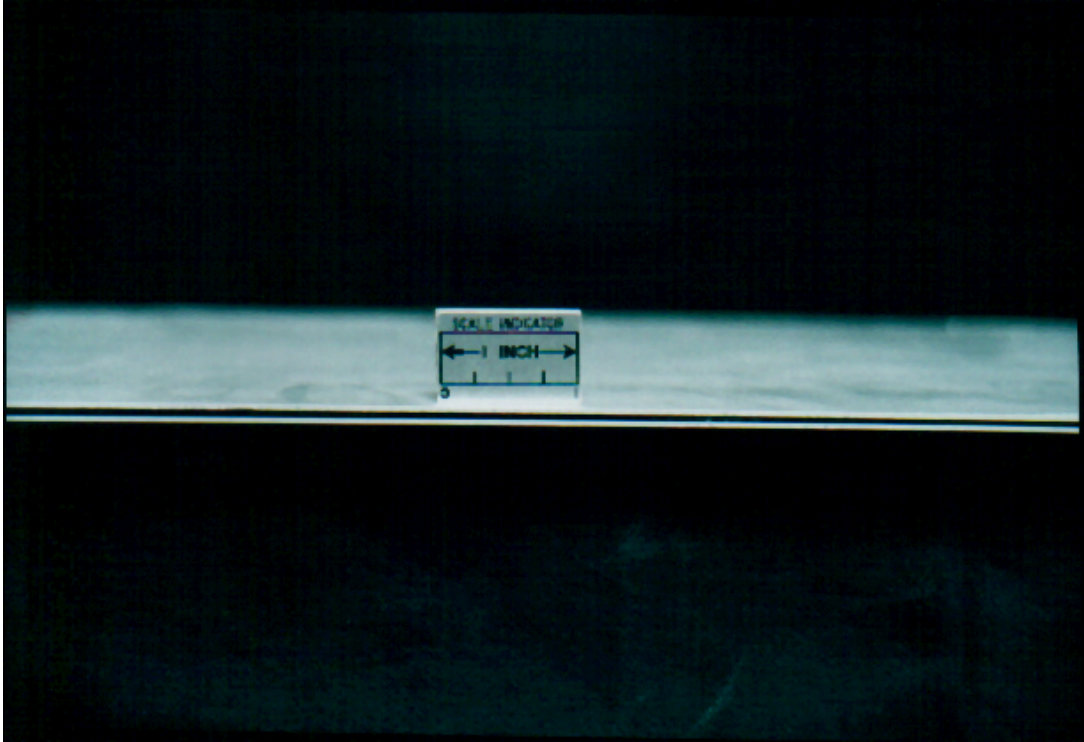


EXHIBIT 7, visual appearance of gap with media ingress



EXHIBIT 8, ultraviolet illumination of media ingress,  
XL on left-hand, type V on right-hand