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Water-Based Pressure Sensitive Paint

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Abstract

Preparation and performance of a water-based pressure sensitive paint (PSP) is described. A water emulsion of an oxygen permeable polymer and a platinum porphyrin type luminescent compound were dispersed in a water matrix to produce a PSP that performs well without the use of volatile, toxic solvents. The primary advantages of this PSP are reduced contamination of wind tunnels in which it is used, lower health risk to its users, and easier cleanup and disposal. This also represents a cost reduction by eliminating the need for elaborate ventilation and user protection during application. The water-based PSP described has all the characteristics associated with water-based paints (low toxicity, very low volatile organic chemicals, and easy water cleanup) but also has high performance as a global pressure sensor for PSP measurements in wind tunnels. The use of a water-based PSP virtually eliminates the toxic fumes associated with the application of PSPs to a model in wind tunnels.

Introduction

PSP measurements provide a means for the recovery of global surface pressure distributions on aerodynamic test articles of interest. The PSP is applied by spray application to the model. Most often this is done in the test section of the wind tunnel. This requires the implementation of temporary exhaust ventilation, cleanup with toxic organic solvents, and respiratory protection from organic vapors. Because wind tunnel test sections are not designed for easy removal of toxic vapors, the levels of such materials in both the test section and the wind tunnel building can exceed allowed Occupational Safety and Health Administration (OSHA) levels, even with temporary exhaust fans. The use of water as the primary paint solvent drastically reduces the presence of these volatile organic chemicals (VOCs). For this reason water-based paints are being used wherever possible, both in consumer and industrial applications. The need for a water-based PSP was the basis for work presented here.

PSPs all contain a luminescent compound that is quenched by oxygen (luminescence is reduced by the presence of oxygen), an oxygen permeable binder (polymer), and solvents. Under the appropriate illumination, the intensity of the luminescence emission from the PSP is inversely proportional to the oxygen concentration, and hence pressure at the surface. The interested reader is directed to several excellent reviews (refs. 1–7) for a more detailed description of the measurement science. In general, PSP measurements require a paint, illumination (i.e., excitation) source(s), scientific-grade CCD camera(s), and optical filters for spectral discrimination between excitation and emission light. Images are captured by a PC and image processing is typically performed on a separate platform. In operation, luminescence intensity data can be acquired in either time-averaged or time-resolved mode. In the more widely employed “intensity method,” images of the painted surface acquired prior to (or immediately following) wind tunnel operation (wind off) are aligned and ratioed with images acquired at run conditions (wind on). The resulting intensity-ratio images are converted into pressure using either a priori calibration data (determined using a pressure/temperature-controlled apparatus in the laboratory), or by applying an in situ calibration using a small population of pressure taps to compensate for PSP temperature sensitivity and photodegradation (refs. 8–19).

Because the polymers used in water-based paints are emulsion polymers (polymers dispersed in water), an oxygen permeable, emulsion polymer had to be synthesized. The resulting emulsion polymer, combined with pigment, water, and other components, leads to a high performance, water-based PSP.
Materials and Method

In order to prepare a water-based PSP it was necessary to produce a water-dispersed emulsion of a polymer that has good oxygen permeability. The polymer chosen was poly-1,1,1-trifluoroethylmethacrylate-co-isobutylmethacrylate at a 1:1 mole ratio (FEM). The emulsion polymer of FEM was then used in the preparation of a water-based PSP.

Synthesis of Polymer Emulsion (Latex)

Materials

• deionized water
• sodium lauryl sulfate
• 1,1,1-trifluoroethylmethacrylate
• isobutylmethacrylate (IBM)
• nitrogen for purging the reaction mixture and maintaining an inert atmosphere during polymerization
• ferrous sulfate heptahydrate solution (0.3 g/200 ml)
• sodium persulfate
• sodium metabisulfite (0.20 g)
• 70-percent tertiary butyl hydroperoxide
• hydroquinone

Procedure

The apparatus shown in figure 1 was assembled and 43 g of water was placed in the 250 ml 3-neck flask. To allow purge nitrogen to escape, a small strip of paper was placed between the stopper and the ground glass fitting of the reaction vessel side arm opening. The long needle for purging the reaction flask was adjusted so that it was below the water level, and the water was purged with nitrogen for at least 10 min. Mixed and added to the separatory funnel were 23.0 g trifluoroethylmethacrylate and 19.4 g isobutylmethacrylate. The monomers were purged with nitrogen for at least 5 min. Sodium lauryl sulfate (0.4 g) was added to the water in the reaction flask and the purge needle was raised above the surface of the liquid. The stirring speed was adjusted to a level just below that which caused bubbles to rise into the side arms. After purging the monomer mixture for at least 5 min, about half the monomer mixture was added dropwise to the reaction mixture. The temperature of the reaction flask was adjusted to 90 °C. Ferrous sulfate solution (0.8 g) was added to the reaction mixture and sodium persulfate (0.2 g) was added to the solution. When making additions to the reaction mixture, the component was rinsed into the reaction flask using a small stream of deionized water from a wash bottle. Sodium metabisulfite (0.2 g) was added and rinsed down, then 2 drops of tert-butyl hydroperoxide were added. Dropwise addition of the monomer mixture was continued until it had all been added to the reaction vessel. The addition of the second half of the monomer took about 10 min. The nitrogen purge of the separatory funnel was discontinued. The nitrogen purge of the headspace above the reaction mixture was continued. The mixture was allowed to react with vigorous stirring at 90 °C for 30 min. It was necessary to adjust the rate of stirring during the reaction to prevent the contents of the flask from being forced up into the flask necks. The temperature controller was reset to 25 °C and the flask was removed from the heating mantle. It was allowed to cool to below 40 °C. The latex was filtered through a #140 (106 µm) wire mesh filter. It was then transferred to a glass jar, a few crystals of hydroquinone were added, and the jar was sealed tightly.

Preparation of Water-Based PSP

Materials

• propylene glycol
• Dowanol
• Byk 346
• DuPont TriPure R-706 TiO2
• Lubrizol 2062
• latex of poly-1,1,1-trifluoroethylmethacrylate-co-isobutylmethacrylate
• water (6.00 g)
• N-methylpyrrolidone (NMP)
• platinum tetra(pentafluorophenyl)porphyrin (PtTFPP)
• glassware
• overhead power blender with appropriate Cowles blade

Procedure

Weighed into a tared container of the appropriate size were 3.00 g Dowanol, 1.85 g propylene glycol, and 0.60 g Byk. The mixture was stirred, then TiO$_2$ was added and blended at low speed (grind) for 25 min using a Cowles blade. Dowanol (6.00 g) and Lubrizol (0.60 g) were weighed into a separate beaker. FEM latex (60.0 g) and water (6.00 g) were weighed into another beaker. NMP (6.0 g) was weighed into a third beaker. PtTFPP (90.8 mg) was weighed and dissolved in the NMP. The NMP/PtTFPP solution was slowly added to the Dowanol/Lubrizol mixture with stirring. This mixture was then added to the FEM latex/water mixture. The latex mixture was added to the grind mixture and blended at moderate speed for 5 min or until thorough blending occurred.

The final paint mixture was filtered through a 106 µm wire screen and transferred to a container and sealed.

Application of Paint to a Model

Paint performance was evaluated in a low speed wind tunnel. The paint was applied using a Paasche Type UT air brush and 40 psi air pressure in a paint spray booth. The model taps were continuously purged with air to prevent clogging. The test article was a “Lockman Wing,” 15.2-cm semispan, 10.2-cm chord, NACA-0012 airfoil with a sweep angle of 20$^\circ$. The model was equipped with 41 pressure taps in three chordwise rows. The paint was air cured for 10 minutes and then gently heated with a hot air gun to anneal the polymer. This annealing procedure gave better adhesion and made cracking of the cured paint less likely. The model was then allowed to air cure for 24 hr. The paint was wet sanded with 1500 grit paper before installing in the test section. The average roughness was 5 µin.

Tunnel Test Conditions

The wind tunnel was a low speed (maximum speed 160 mph), closed-cycle with a 10-in. by 12-in. test section. For this test the wind speed was 160 mph and the angle of attack was 20$^\circ$.

Results

The water-based paint is easily applied by spraying. When properly applied, the cured paint was smooth without tack. When applied on aluminum surfaces no primer was required; however, adhesion to stainless steel was poor and the use of a self-etching primer was necessary for acceptable adhesion. It was found that the water-based PSP was very sensitive to surface contamination of the test object. The slightest presence of oil or silicone caused the paint not to coalesce or to “fisheye.” It was found that the best cleaning procedure was wet sanding (2000 grit paper) with a detergent solution. Water-based paints typically are slow to cure and this one is no exception. It required 24 hr at room temperature to sufficiently cure for testing. Although curing of water-based paints continues for several weeks, no change in the performance of the paint was observed during the test period. The paint may be wet sanded to remove any rough spots caused by dust particles, or to achieve a desired smoothness. After wet sanding with 1500 grit paper it had a typical roughness of less than 5 µin.

Performance of the water-based PSP (WBPS) was essentially the same as that for a solvent-based PSP using FEM/IBM as the binder. A typical response or calibration curve is shown in figure 2. A typical pressure sensitivity at atmospheric pressure is 6.2 percent/psia, or a slope of 0.91 for a plot of $I_o/I$ versus $P/P_o$. The temperature sensitivity is typically −1.4 percent/°C. Although there is a slight
bending over of the Stern-Volmer plot, response over a typical wind tunnel pressure test range is essentially linear.

Global pressure images of the test model are shown in figures 3(a) and (b), and the correlations between the taps and the pressure as measured from the PSP are shown in figures 4(a) and (b).

**Concluding Remarks**

The combination of an oxygen permeable polymer and a platinum porphyrin-type luminescent compound in a water matrix to give a PSP that performs well without the use of volatile, toxic solvents represents an important contribution to PSP paint options. The primary advantages of a water-based PSP are reduced contamination of wind tunnels in which it is used, lower health risk to its users, and easier cleanup and disposal. This also represents a cost reduction by eliminating the need for elaborate ventilation and user protection during application.

**References**


Figure 1. Apparatus for synthesizing FEM emulsion polymer.

Figure 2. Pressure (P) response curves at different temperatures (T) for water-based PSP.
Figure 3. Global pressure distribution.

(a) Ratio of run image to pre–wind-off image.

(b) Ratio of run image to post–wind-off image.
Figure 4. Correlation between taps and PSP pressure data.
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Pressure sensitive paint; Polymer emulsification; Optical pressure measurements; Water-based paints