Sol-gel based Pressure Sensitive Paint for Wind Tunnel and Aeronautics Application

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A new unsteady Pressure Sensitive Paint (PSP) based on a nanostructured sol-gel coating has been developed and tested on a steel model of a civil aircraft in a transonic wind tunnel of ONERA. The results, which are in good agreement with pressure measurements, make this nanoporous coating a promising PSP to study aircraft models in unsteady conditions.

Pressure Sensitive Paint (PSP) is a global surface pressure measurement for a large domain of velocities from low speed to supersonic steady state flows. The fundamental operating principle of PSP is the oxygen quenching of luminescence from luminophores dispersed in the paint. Light intensity emitted by the paint is measured by a photodetector, providing a global map of pressure distribution over the probed surface. The extension of the PSP technique to unsteady measurements is a new challenge that requires the development of new paints with a response time several orders of magnitude below that of conventional PSP. Among the several ways to reduce the response time of the paint while maintaining a high sensitivity to pressure and a high intensity of luminescence, the most efficient are based on the introduction of porosity within the coating to increase the diffusivity of O_2. A fast responding PSP based on porous anodized aluminum (AA-PSP) with the dye adsorbed on the surface, achieving a very short response time (t ~ 100s µs) has been developed. However, sensitivity to humidity, the low intensity of emission, and the limiting structuration process (immersion in an acid bath of Al parts) make this approach difficult to implement.

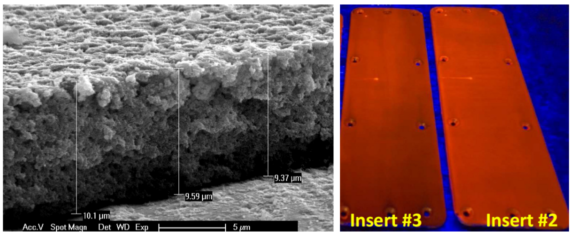

Figure 1: (Left) SEM micrograph of the nanoporous silica layer cross-section of a sample similar to insert #3 (10 µm thick); (Right) Fluorescence pictures (excitation 365 nm) of nano-PSP homogeneously treated inserts #2 and #3.

In order to address those issues, a new method has been investigated at CSEM: to develop a sol-gel based nanoporous pressure sensitive paint (nano-PSP) with low response time and high luminescent intensity, which would provide an increased frequency bandwidth (> 2 kHz). As a result, the influence of some nanoporous film features on the sensing performances was established (Figure 1). More specifically, the pore diameter and the total pore volume have a decisive effect on the sensitivity of dye loaded films for O_2 concentration measurement. Moreover, the high film transparency enables optical measurements. Finally, the films contain a crosslinked polymer that improves their mechanical resistance. All these characteristics make these nanoporous films relevant candidates for the optical measurement of O_2 pressure in a transonic wind tunnel. For this purpose, a few challenges have been addressed. First, the nanoporous PSP composition was designed in order to obtain suitable pore sizes enabling low response times, film thickness for an optimal luminescence intensity, and mechanical stability to support the wind impact. Secondly, the functionalisation process with the luminescent dye was modified to improve the sensitivity to O_2, the luminescence intensity and homogeneity over the whole surface area. Finally, nanoporous layer deposition and functionalisation processes have been scaled up to cover non-even substrates with a homogeneously distributed luminescence and O_2 sensitivity.

The first generation of this PSP has a pressure sensitivity around 0.35 %/ kPa, which is lower than that of the AA-PSP. However, its luminescence intensity is about three to five times higher than that of the AA-PSP, resulting in a favourable compromise for a fast acquisition rate, which requires short exposure time. This first generation of nanoporous PSP was tested on a civil aircraft in the ONERA S2MA transonic wind tunnel. PSP measurements were achieved at a frame rate up to 5000 fps (Figure 2). Useful results as RMS, PSD and coherence maps were obtained and compared favourably with those of pressure sensors. PSP measurements provide a high density of spatial information over a large area, which is difficult to achieve with pressure sensors. These results have been presented at the well-known AIAA aeronautics conference [1].

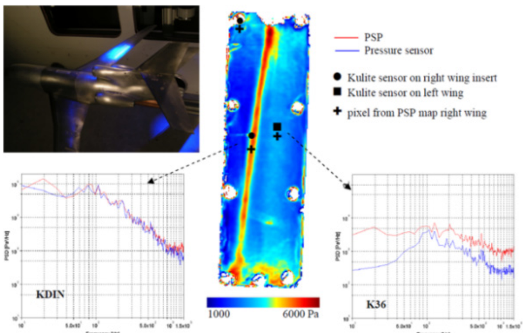

Figure 2: RMS map and PSD from nano-PSP (Insert #3). Pressure Pi_0 = 185 kPa, speed M = 0.875, incidence α = 1.11°, acquisition frequency F_{acq} = 5000 fps. Photograph of the insert on the model.

However, this first generation of nanoporous PSP can still be improved. Since the test was conducted in a wind tunnel, a second generation of the nanoporous PSP has been under development. The pressure sensitivity has been improved while maintaining the high luminescence intensity of the first generation. A wind tunnel test of this new generation is scheduled for late 2015. Future developments will aim at reducing the temperature sensitivity and improving the usability on larger 3D surfaces.

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[1] Y. Michou, B. Deleglise, F. Lebrun, E. Scolan, A. Grivel, R. Steiger, R. Pugin, M.-C. Merienne, Y. Le Sant, Proc. 31st AIAA 2015, 2408