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Innovative Pressure Sensitive Paints (PSPs) labeled with rare earth metal complexes dedicated to aerodynamic tests in wind engineering

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SUMMARY (10 pt)
This study presents innovative pressure sensitive paints for aerodynamic measurements in wind engineering based on polymeric solvent quenched pressure sensitive paint systems labeled with rare earth metal complexes. The proposed materials use derivatives of [tris(4.4.4-trifluoro-1-(2-thienyl)butane-1.3-dionato)]europium(III) as luminophores embedded in tailored polymer matrices. In contrast to conventional oxygen quenched PSPs the new systems operate through solvent quenching which offers high sensitivity near atmospheric pressure strong emission and reduced temperature interference. The developed coatings are intended for high resolution pressure mapping on building models in wind tunnels including surfaces of complex geometry. These materials may improve the accuracy of wind load assessment of buildings and prediction of adverse atmospheric effects in urban areas.

Keywords: Pressure Sensitive Paints, pressure mapping, wind tunnels

1. INTRODUCTION

The growing number of high-rise buildings and geometrically complex structures in urban areas increases the need for accurate aerodynamic testing in wind tunnels. In engineering practice classical point pressure measurement techniques are still widely used. Their main limitation is the low spatial resolution of the measurement as well as the difficulty of reproducing pressure distributions in edge regions and on surfaces with complex shape. It has also been shown that close aerodynamic interference between adjacent high-rise buildings can significantly affect local pressure distributions overall wind actions and pedestrian level flow conditions which further supports the need for full field pressure mapping methods in wind engineering (Flaga et al., 2018). Classical Pressure Sensitive Paints were originally developed mainly on the basis of oxygen quenching of luminescence (Gouterman, 1997). However, such systems were not designed for high sensitivity near atmospheric pressure which is typical of wind tunnel studies on building models. Solvent Quenched Pressure Sensitive Paints (SQ-PSP) offer a promising alternative because they enable high resolution pressure mapping in the pressure range relevant to wind engineering. Previous studies demonstrated the usefulness of europium complexes as pressure sensitive luminophores provided a quantitative interpretation of the SQ-PSP response to pressure and confirmed the applicability of new PSP formulations for pressure mapping on building models under turbulent flow conditions in a wind tunnel (Pilch et al., 2020; Pilch et al., 2021; Pilch et al., 2024; Topa et al., 2018).

2. METHODS

This study focuses on polymer-based SQ-PSP systems that use solvent quenching of luminescence instead of conventional oxygen quenching. Particular attention was given to the PSP-Eu2 formulation containing 0.1 wt.% Eu(NTTA)3(TOPO)2 immobilized in a BMA-co-DEGDMA matrix with 25 wt.% DOF. Calibration was performed in VTM and CTM modes by recording luminescence spectra under applied load or pressure. In VTM mode measurements were carried out semi-automatically using a MATLAB 2018a script with loads applied manually by analytical weights or an aluminium piston system. In CTM mode measurements were conducted automatically in a pressure chamber after defining pressure range measurement step integration time and temperature. The sample was tested either with or without an upper microscope slide which affected the possible contribution of oxygen quenching. In both modes the results were exported to Excel. The material was designed for wind tunnel testing of civil engineering models. Pressure sensitivity was evaluated in the range from -0.5 bar to +0.5 bar in both CTM and VTM modes. Final calibration was performed against the reference point pressure sensor system at the Wind Engineering Laboratory of Cracow University of Technology. Tests were carried out in a subsonic mixed-circuit wind tunnel with a 10 m long and 2.2 m wide test section of variable height from 1.4 m to 1.6 m and a maximum mean air velocity of 40 m/s under turbulent flow conditions corresponding to terrain category IV. Application tests included pressure mapping on a measuring plate at 18 m/s for wind attack angles from 0° to 180°. The grid-based maps from point sensors were reconstructed by interpolation from discrete points whereas PSP provided a continuous pressure field with higher spatial resolution. Therefore, visual similarity between maps should not be interpreted as equivalent measurement resolution.

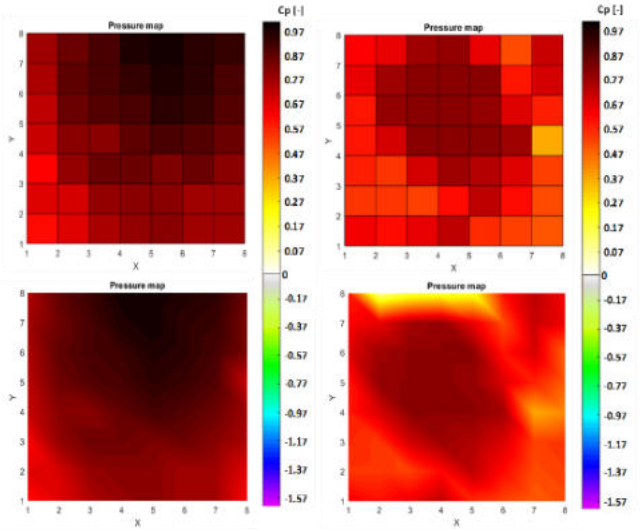
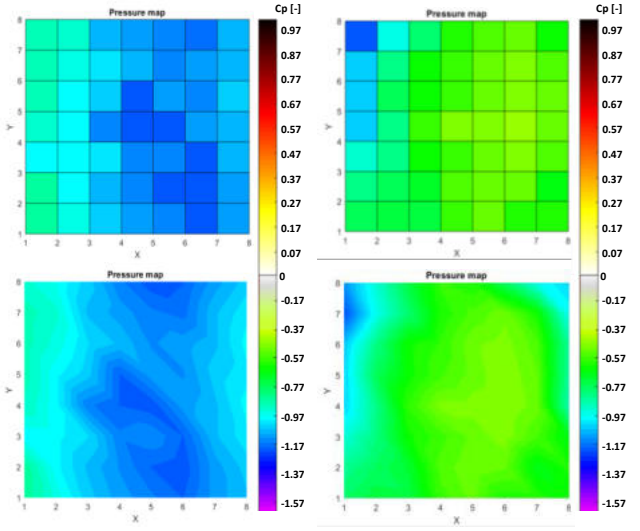
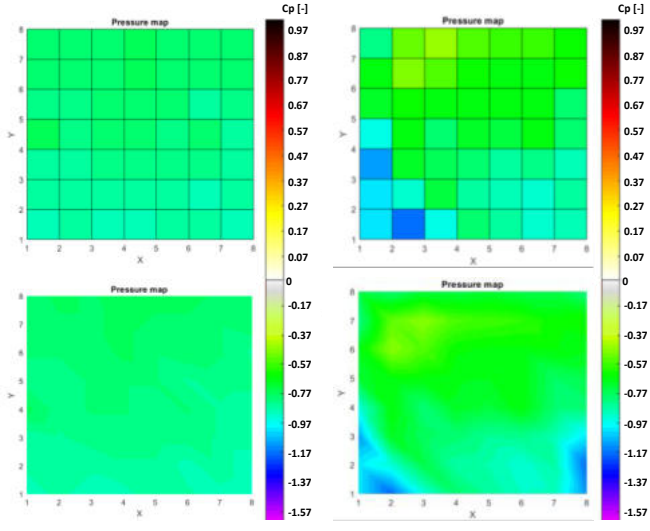
3. RESULTS &DISCUSSION

The PSP-Eu2 system showed pressure sensitivity under oxygen free conditions equal to SP = 0.57 %/kPa and SN = 0.50 %/kPa in CTM mode. The obtained characteristics allowed final calibration of the system against the reference point pressure sensors both for positive pressure and for high suction conditions.

In wind tunnel tests pressure maps were obtained for the 18 m/s case and for a series of wind attack angles which suggested the applicability of PSP-Eu2 for spatial reconstruction of the pressure field on the tested surface. The results indicate that the system based on derivatives of [tris(4.4.4-trifluoro-1-(2-thienyl)butane-1.3-dione)]europium(III) can operate within the parameter range characteristic of building model studies in wind engineering.

For wind incidence angles of 0° and 180°, both methods indicate an almost uniform pressure distribution and show good overall agreement. At 0°, a uniform region of positive pressure is observed whereas at 180° the pressure field remains nearly homogeneous with only minor local variations in the PSP results. At 90°, both methods reveal suction-dominated conditions. However, SQ-PSP reproduces the general pressure pattern with smoother gradients and reduced local extrema compared with the reference point pressure sensor system. Overall, SQ-PSP accurately captures the main pressure distribution trends, particularly in the windward pressure range, while its quantitative agreement is weaker in the suction range where it is more suitable for qualitative identification of negative pressure zones.

Table 1. Compilation of pressure distribution maps on the tested surface of the measuring plate, determined at LIW PK using the reference technique of point pressure sensors and the PSP-Eu2 system, for a wind speed of 18 m/s and various wind angles of attack (A).

A [°]	Point Pressure Sensors - LIW PK	SP-Eu2 System - LIW PK
0		
90		
180		

4. CONCLUSIONS

The presented SQ-PSP system labeled with derivatives of [tris(4.4.4-trifluoro-1-(2-thienyl)butane-1.3-dione)]europium(III) show significant potential for aerodynamic studies on building models. For the PSP-Eu2 formulation useful pressure sensitivity and good agreement with the reference technique were obtained in the windward pressure range. At the same time limited accuracy of the system was observed in the suction range. In its present form the system may therefore be regarded as a promising tool for pressure distribution mapping under wind pressure conditions whereas its application to quantitative analysis of negative pressure zones still requires further optimization.

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