Research on Ultrafast Response Pressure-Sensitive Paint Suitable for Measuring Unsteady Shock Wave Phenomena in Atmospheric Pressure Environments

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ABSTRACT

In the elucidation of shock wave phenomena, various flow visualization techniques are employed to understand their dynamics. Prominent methods include shadowgraphy, schlieren photography, and interferometry, which have been widely used in experimental studies to visualize various shock wave phenomena. However, these visualization techniques are generally used for qualitative measurement, and they do not allow for the quantitative capture of pressure and temperature changes on the measurement target as the shock wave propagation. To quantitatively measure pressure and temperature on the surface of the test model, it is necessary to use mechanical unsteady pressure and temperature sensors in conjunction with these flow visualization techniques.

Amidst these challenges, pressure-sensitive paint (PSP) has attracted attention as a method capable of quantitatively and areally measuring the pressure on the target without influencing the flow field. PSP utilizes fluorescent dyes with oxygen quenching capabilities, functioning as functional molecular sensors that measure pressure changes based on variations in luminescence intensity as the surrounding pressure changes. This method allows for the acquisition of pressure across all PSP-painted areas, unlike traditional point measurement methods using mechanical sensors, and thus enables areal understanding of the pressure field. Additionally, because pressure measurement with PSP is derived from changes in luminescence, it offers advantages as a non-contact and non-invasive measurement technique. These characteristics suggest that PSP could become an increasingly effective experimental measurement method for studying shock wave phenomena.

However, when considering the measurement of unsteady shock wave phenomena using PSP, the luminescence intensity of the PSP must adequately follow the rapid changes in pressure on the measurement target. If this is not achieved, it becomes difficult to capture the unsteady shock wave phenomena accurately. Therefore, for precise measurement of shock waves with PSP, the PSP must have excellent time response characteristics, specifically in how the luminescence intensity changes in response to pressure changes.

Known for its high time response, Anodized Aluminum PSP (AA-PSP) is a type of unsteady PSP that is created by adsorbing dyes onto an anodized aluminum surface. Notably, an ultrafast-response PSP developed by Numata et al., which involves anodizing aluminum with phosphoric acid followed by dye adsorption, is known for recording a 90 % rise time of 0.81 microseconds. This PSP has also successfully visualized unsteady shock wave phenomena passing through a cylinder. Recently, attempts have been made to utilize AA-PSP for investigating the propagation of shock waves originating from supersonic projectiles and for measuring pressure fields on supersonic free-flight bodies. Particularly, its application is being explored for aerodynamic testing using ballistic ranges. Ongoing research continues to improve PSPs' time response and other properties, with modifications being made to adapt this measurement technique to various unsteady shock wave phenomena.

This paper presents the development results of unsteady AA-PSP aimed at quantitatively measuring rapidly changing unsteady pressure fields caused by various unsteady shock wave phenomena in atmospheric pressure environments, such as shock waves from explosions of explosives and sonic booms. Mainly, it details the characteristics of AA-PSP developed by our team using a new fabrication method, comparing it to traditional AA-PSP in terms of achieved time response and pressure sensitivity. Additionally, we will introduce specific applications of the developed AA-PSP in experiments using shock tubes and other shock wave-related equipment, demonstrating its applicability to unsteady shock wave phenomena.

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