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Evaluating the Reliability of Coated Surfaces for Thermographic Phosphor Temperature Measurement

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1. Introduction

Thermographic phosphor temperature measurement is an advanced optical technique for remote temperature sensing, utilizing the temperature-sensitive luminescence properties of phosphor materials [1,2]. This method offers significant benefits in various high-temperature applications, but its reliability and accuracy can be compromised by thermal and mechanical degradation of the phosphor coating [3,4]. These degradation processes can cause changes in luminescence intensity and spectral characteristics, potentially resulting in significant measurement errors.

Previous studies have investigated various aspects of thermographic phosphor coatings, including their high-temperature survivability and adhesion performance [5,6]. However, there is a lack of comprehensive research quantifying the adhesion strengths of films deposited using different methods, particularly for thin film techniques [7]. This knowledge gap is primarily attributed to the absence of reliable methods for quantifying adhesion and wear resistance.

This study aims to evaluate the reliability of thermal imaging phosphor coatings fabricated using BAM:EuMn phosphors and ZYP-BNSL ceramic binders in terms of both thermal degradation and mechanical degradation. By analyzing the thermal degradation characteristics and calibration curves of specimens fabricated with different phosphor powder and binder mix ratios and paint spray volumes, we derive the optimal conditions that exhibit the best temperature-emission intensity characteristics during temperature measurement. We also evaluate the mechanical bonding and reliability of the thermally degraded coatings using an in-house developed roller abrasion test rig.

2. Experimental procedure

The thermographic phosphor used in this study was BAM:EuMn ($BaMgAl_{10}O_{17}$:EuMn) from TOKYO KAGAKU KENKYUSHO CO., LTD. ZYP-BNSL binder (ZYP Coatings Inc., Oak Ridge, USA) was chosen as the ceramic binder. The phosphor paint specimens were fabricated by air-spraying on copper flat plate specimens (50x50x1 mm).

Eight specimens with different conditions were prepared to compare and analyze the luminescence characteristics and mechanical durability according to the combination ratio of phosphor powder and ceramic binder, and the amount of paint sprayed. Additionally, four specimens with different surface roughness were prepared using the same paint composition to compare and analyze the mechanical durability of the paint according to the surface roughness of the base metal specimen.

A self-developed reciprocating rolling abrasion tester (Fig.1) was employed to assess the mechanical durability of the coating. The roller moved at a speed of 5.3cm/s while applying a vertical load of 1 kgf to the specimen. The specimens that had undergone thermal degradation at 300°C for 24 hours were used for the abrasion tests. Images were acquired after every 100 reciprocations to compare the extent of damage to the specimens.

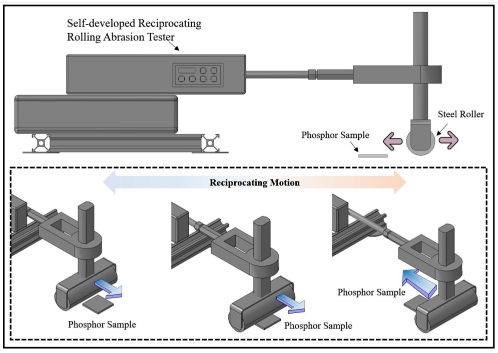

Fig. 1 Self-Developed Rolling Wear Tester Schematic Image

3. Results and discussion

The degree of luminescence intensity degradation due to thermal degradation was found to depend on the ratio of paint components. The decrease in intensity value due to thermal degradation was significant with the increase of binder content. Sample with a phosphor powder-to-binder ratio of 1:0.5, showed a 64.9% reduction in luminescence intensity after being annealed at 300°C for 24 hours. In contrast, Sample with a phosphor powder-to-binder ratio of 1:4 which had the highest binder ratio, exhibited the most substantial degradation with an 89.4% reduction in luminescence intensity. The experimental data demonstrated an inverse relationship between binder content and temperature sensitivity of the intensity ratio. As the binder concentration increased, the intensity ratio exhibited diminished variation with temperature fluctuations.

The mechanical durability was evaluated as a function of binder content and paint spray quantity. The optimal durability was observed when the weight ratio of binder to powder was 1:2. Lower ratios predominantly resulted in Cohesion Failure, while higher ratios led to Adhesion Failure. A minimum threshold of paint spray quantity was found necessary to ensure adequate thickness. Insufficiently sprayed paint exhibited severe Cohesion and Adhesion Failure under reciprocating roller conditions, while paint above a certain thickness demonstrated superior durability. Excessively low surface roughness of substrate (i.e., very smooth surfaces) facilitated Adhesion Failure. When the test subject surface for phosphor paint application was too smooth, it was anticipated that Failure may occur easily due to thermal degradation, expansion, and contraction. (Fig.2)

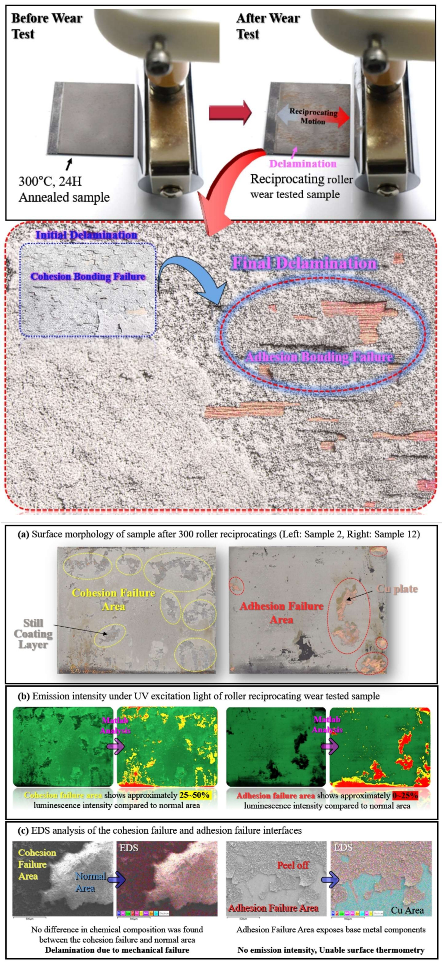

Fig. 2 Specimen surface delamination geometry characteristics after roller wear test

Conclusion

This study provides a comprehensive evaluation of the reliability of thermographic phosphor coatings for temperature measurement, focusing on both thermal and mechanical degradation aspects. The optimal durability was observed when the weight ratio of binder to powder was 1:2, balancing cohesion and adhesion forces. A minimum threshold of paint spray quantity was necessary to ensure adequate thickness and durability. Surface roughness of substrate played an important role, with an overly smooth underlying surface promoting adhesion failure. Dynamic temperature measurements using optimized coating conditions demonstrated excellent durability and successful temperature measurement under simulated harsh conditions.

These findings contribute to improving the applicability and reliability of thermographic phosphor-based temperature sensing technology in demanding thermal environments. Future work could focus on further optimizing the coating composition and application methods for specific industrial applications and exploring the long-term stability of these coatings under various environmental conditions.

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