Optical properties of Al$_2$O$_3$ and Al$_2$O$_3$/BaSO$_4$ reflecting diffusers processed with plasma powder spraying

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Integrating spheres, diffusers

- Integrating spheres
  - Total luminous flux measurements
  - Reflectance/Transmittance measurements
  - Components of photo-detectors

- Reflecting diffusers
  - Radiance/Luminance standards
  - Reflectance standard (diffuse, reflectance factor, BRDF)
  - Installation in optical systems to uniform radiation
Consideration for industrial use

Integrating spheres and reflecting diffusers used for...

- Products inspection (high-speed testing)
- Field measurements

have problems such as …

- **Damage** (mechanical vibration, frequent attachment/detachment of products etc.)
- **Deterioration** (due to environmental factor etc.)
- **High-cost**

They need to have …

- Optical properties similar to those used in laboratories
- **High durability** against mechanical shocks etc.
- **Cost effectiveness** (material, preparation process)
Major Reflecting Diffusers

- Major process to prepare reflecting diffusers (or integrating spheres)

  - **Painting**: $\text{BaSO}_4$
  - **Pressing**: $\text{BaSO}_4$, PTFE etc.
  - **Sintering**: Ceramic tiles ($\text{Al}_2\text{O}_3$ etc.)
  - **Resin**: PTFE
  - **Smoking**: MgO

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Plasma powder spraying

Electrically generated plasma flame + Powdered material → Heating, Melting and accelerating → Impact on substrate and rapid cooling → Deposition over the substrate

Coating with high mechanical strength using various types of materials
Objectives

➢ Investigation on **basic optical properties** of $\text{Al}_2\text{O}_3$ based reflecting diffusers processed with **plasma powder spraying** technique

➢ Approaches **to improve reflection properties** (reflectance, spectral flatness) by means of ...
  • Containing $\text{BaSO}_4$ as compound
  • Another (new) thermal spraying technique
Experimental setup

- Reflecting diffusers based on plasma powder spraying
  Targeted material: Al$_2$O$_3$
  *Thickness: 0.2 mm, 0.4 mm, 0.6 mm
  *Substrate: Aluminum (50 x 50 x 3) mm

- Basic Optical Properties
  - Reflectance
  - Spatial distribution
  - Ageing
  - Exposure to UV radiation

- Containing BaSO$_4$ as compound
  Al$_2$O$_3$/BaSO$_4$ (3:1) and Al$_2$O$_3$/BaSO$_4$ (7:1)

- New thermal spraying process
  Suspension thermal spraying
Methods for Evaluation (1)

1) Spectral Diffuse Reflectance

- **Instrument:** Calibrated spectrophotometer (PerkinElmer, Lambda-900)
- **Range:** 250 nm to 900 nm (5 nm interval)
- **Bandwidth:** about 3 nm
- **Geometry:** \(8^\circ:di\) (SCI)

\[
\rho_{test}(\lambda) = \frac{R_{ref1}(\lambda)}{R_{std}(\lambda)} \cdot \frac{R_{test}(\lambda)}{R_{ref2}(\lambda)} \cdot \rho_{std}(\lambda)
\]
Methods for Evaluation (2)

2) Spatial Distribution of Reflected Radiation

- **Instrument:** Gonio-Reflectometer (Murakami, GP-200)
- **Range:** 400 nm to 700 nm (16 interference filters)
- **Bandwidth:** ~10 nm
- **Geometry:**
  - Incident Angle: 0° incidence
  - Receiving Angle: -45° to 90° (1° interval)

3) UV radiation exposure

- **Source:** Hg/Xe lamp
- **Irradiation area:** 100 mm x 100 mm
- **Uniformity:** < 2.5 %
  (for surface reforming)
- **Dose:** 50 J/cm², 100 J/cm², 150 J/cm² (at 365 nm)
Mechanical Strength

- Vickers Hardness (Load: 0.5 N)
  \( \text{Al}_2\text{O}_3 \) thermal spraying: ~500 HV
  \( \text{Al}_2\text{O}_3/\text{BaSO}_4 \) (3:1) thermal spraying: ~400 HV
  cf.) \( \text{BaSO}_4 \) sprayed with PVA-aq: N/A

- Strength test
  No damage after strength test with intense vibration and scratch using a metal spatula.
Reflectance vs. Thickness

Fig. Spectral diffuse reflectance of $\mathrm{Al}_2\mathrm{O}_3$ plasma powder spraying samples with different thickness.
Effect on Containing BaSO$_4$

Fig. Spectral diffuse reflectance of Al$_2$O$_3$ and Al$_2$O$_3$+BaSO$_4$ (3:1) samples processed with plasma powder spraying

Increase of reflectance from 350 nm to 500 nm
Reflectance Uniformity

Reflectance non-uniformity: < 0.2 % (worst case: < 0.5 %)

Fig. Reflectance non-uniformity of \( \text{Al}_2\text{O}_3 \) and \( \text{Al}_2\text{O}_3 + \text{BaSO}_4 \) (3:1) samples processed with plasma powder spraying samples
**Spatial Distribution (1)**

*Normalized at the value of 45°*

**Fig. Spatial distribution of reflected radiation from Al₂O₃ and Al₂O₃+BaSO₄ (3:1) samples processed with plasma powder spraying**
Spatial Distribution (2)

$\text{Al}_2\text{O}_3/\text{BaSO}_4\ (3:1), \ t = 0.4 \text{ mm}$

Fig. Spatial distribution of reflected radiation from $\text{Al}_2\text{O}_3$ and $\text{Al}_2\text{O}_3+\text{BaSO}_4\ (3:1)$ samples processed with plasma powder spraying
Ageing Characteristics (1)

Large decrease in reflectance around 300 nm region

Fig. Change of spectral diffuse reflectance after a half-year storage for Al$_2$O$_3$ and Al$_2$O$_3$+BaSO$_4$ (3:1) samples
Ageing Characteristics (2)

Fig. Change of spectral diffuse reflectance after a half-year, a one year and two years storage for $\text{Al}_2\text{O}_3$ and $\text{Al}_2\text{O}_3+\text{BaSO}_4$ (3:1) samples

Saturation of ageing effect?
Exposure to UV Radiation

Fig. Reflectance change of an Al₂O₃ sample processed with plasma powder spraying due to UV exposure
Suspension thermal spraying

Supplying the sample by means of suspension (aqueous solution) --- nano-structured coatings

1) Suspension HVOF spraying
2) Suspension Plasma spraying

Al₂O₃ samples
Suspension thermal Spraying

Fig. Spectral diffuse reflectance of Al₂O₃ samples based on (1) plasma powder spraying, (2) HVOF suspension spraying, and (3) plasma suspension spraying.
Summary

- $\text{Al}_2\text{O}_3$ and $\text{Al}_2\text{O}_3/\text{BaSO}_4$ (3:1) reflecting diffusers processed with plasma powder spraying technique
- Realization of reflecting diffusers with high mechanical strength
- Investigation of the basic optical properties
  - Reflectance of approximately 0.85 to 0.90 in the visible range
  - Improvement of reflectance from 350 nm to 500 by Adding $\text{BaSO}_4$
  - Reflectance uniformity $< 0.5\%$ (1σ)
  - Spatial distribution of reflected radiation: approximate to lambertian
- Ageing properties
  - decrease of reflectance around 300 nm to 400 nm
  - saturation effect
  - restoration of reflectance due to UV exposure
- Needs for further investigation, especially to clarify the mechanism
- Potential of suspension thermal spraying