

The self-sense monitoring of coating wear by in situ SiO₂-coated SrAl₂O₄:Eu²⁺, Dy³⁺ luminescent particles

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Abstract. Monitoring of coating health was achieved by embedding sensor materials SrAl₂O₄:Eu²⁺, Dy³⁺ in tribological coatings, and luminescence spectra of sensor materials were used for damage sensing by monitoring the intensity of the spectra. When the light emitting from coating disappeared, it indicated the coating wearied off and the substrate exposed. But emission intensity of the SrAl₂O₄:Eu²⁺, Dy³⁺ in tribological coating was quenched in preparation process which will weaken the effect of coating instructions. In this work, SiO₂-coated SrAl₂O₄:Eu²⁺, Dy³⁺ were coupled with Cu-14Al-X alloy powders to form sensor composite coating by supersonic plasma spraying. The composite coatings before and after SiO₂-coating were compared of phase composition, microstructure, luminescence properties and tribological performance. The composite coating shows not only good resistance to wear but also exhibits strong green light emitting under UV light. The SiO₂-coating could prevent phosphors quenching due to high temperature in the supersonic plasma spraying process, and could repair the wear surface. The composite coating with SiO₂-coated SrAl₂O₄:Eu²⁺, Dy³⁺ particles had very stable friction coefficient, When the coating ratio of SiO₂ was 10% for SrAl₂O₄:Eu²⁺, Dy³⁺ particles, the luminescent properties and friction property of composite was optimal.

1. Introduction

Recently, a novel self-sensing tribological coating were developed for monitoring wear using handheld battery-operated UV lights at the operating site which can be fast and conveniently applied in periodic inspections. In some reports^[1-2], the Cu-14Al-X were coupled with SrAl₂O₄:Eu²⁺, Dy³⁺ phosphorescence forming the self-sensing tribological coating and the phosphors particles are incorporate into wear-resistant coating served as sensor materials for warning coating worn off and replacement. But the luminescence intensity decreased in coating and the quenching behavior of phosphors will be harmful to the indication of the coating. For improving the anti-degradation of SrAl₂O₄:Eu²⁺, Dy³⁺ during thermal spraying, the most effective technique is to coat the surface of phosphor particles with protective materials^[3-6].

In this paper, the surface of SrAl₂O₄:Eu²⁺, Dy³⁺ was coated with SiO₂ by Sol-gel process. Not only the microstructures and luminescent properties of the coatings but also tribological properties are investigated before and after coating SiO₂.



2. Experimental

The aluminum bronze metals (Cu-14Al-X) were melted at 1200 ~ 1260 °C, followed by water cooling atomization to form the alloys powders as listed in Table 1.

Table.1 High-aluminum bronze composition (Cu-14Al-X)

Element	Cu	Al	Fe	Ni	Balance.
wt. %	70~80	12~16	2.0~4.5	0.5~2.0	0.5~2.0

The core-shell structured $\text{SrAl}_2\text{O}_4:\text{Eu}^{2+}, \text{Dy}^{3+}$ microspheres were prepared by a simple sol-gel method and the molar ratio of tetraethoxysilane, ethanol and water was 1:3:5. The tetraethyl orthosilicate (TEOS) was served as silicon source. A small amount of ammonia was dripped into these solutions as catalyst for hydrolyzing of TEOS, and the pH value was kept at 4-5; After being stirred for 2h, SiO_2 -coated $\text{SrAl}_2\text{O}_4:\text{Eu}^{2+}, \text{Dy}^{3+}$ phosphors with various SiO_2 addition content (5wt%, 10wt%, 15wt% and 20wt%) were obtained.

Cu-14Al-X / $\text{SrAl}_2\text{O}_4:\text{Eu}^{2+}, \text{Dy}^{3+}$ composite coating doped with 10% SiO_2 coating for the phosphors were prepared on 45# carbon steel substrate by supersonic plasma spray. Wear tests were done on a pin-on-disk wear tester (MMW-1A). The wear test mode is illustrated in Fig. 1, the Phosphorescent composite coating sample acted as the disk. The test load is 35N, 70N, 110N, speed is 80r/min.

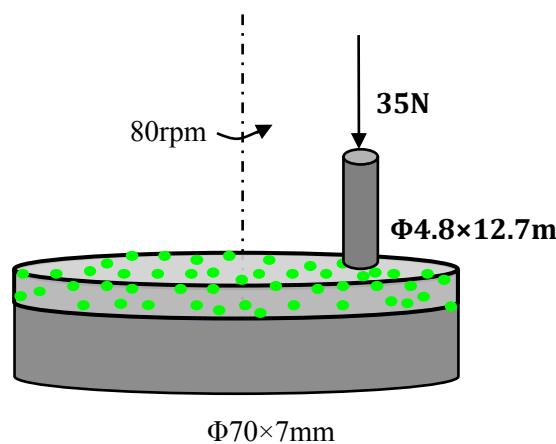


Fig. 1 Wear testing schematic diagram

3. Results and Discussion

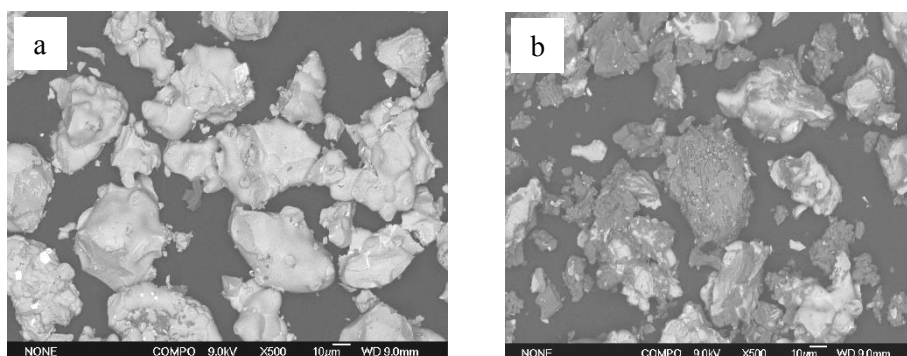


Fig.2 SEM micrographs of phosphor before and after coating: a uncoated; b after SiO_2 coated

SEM images of pure $\text{SrAl}_2\text{O}_4:\text{Eu}^{2+}, \text{Dy}^{3+}$ (Fig.2a), and $\text{SrAl}_2\text{O}_4:\text{Eu}^{2+}, \text{Dy}^{3+}$ microspheres coated by a layer of SiO_2 shell (Fig.2 b) were showed in Fig.2. The surface of the coated sample particles are relatively smooth, and uniform, complete, and with high density. The composition of the film can be characterized by EDX. The EDX (table.2) confirms the above elements and silicon (Si) in the SiO_2 -coated

$\text{SrAl}_2\text{O}_4:\text{Eu}^{2+},\text{Dy}^{3+}$ samples. The results indicate that the surfaces of $\text{SrAl}_2\text{O}_4:\text{Eu}^{2+},\text{Dy}^{3+}$ phosphors are successfully covered with SiO_2 thin layer via the sol-gel treatment process.

Tab.2 Element content of phosphor before and after coating

Sample (Region)	The quality of elements (wt.%)			
	Al	Sr	O	Si
(a) -1	25.18	44.22	36.60	
(b) -2	1.23	2.1	42.55	54.12

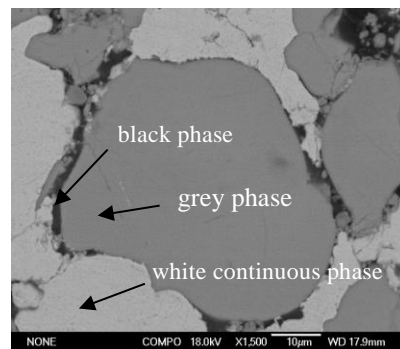


Fig. 3 The typical SEM micrographs of the composite fluorescent coatings with SiO_2 coated Cu-14Al-X / $\text{SrAl}_2\text{O}_4:\text{Eu}^{2+},\text{Dy}^{3+}$ composite coating doped with SiO_2 coating for the phosphors were prepared on 45# carbon steel substrate by supersonic plasma spray and the typical SEM micrographs of the composite fluorescent coatings were showed in Fig.3. These coatings all composed of white continuous phase, grey phase and black phase. The white continuous phase is the Cu-14Al-X powders, thus it is concluded the composition of Cu-14Al-X powder has no changed before and after supersonic plasma spray. In Fig.3 clear interfaces exist amongst white continuous phases, grey phase is the $\text{SrAl}_2\text{O}_4:\text{Eu}^{2+},\text{Dy}^{3+}$ phosphors with the SiO_2 coating around the grey phase as black phase.

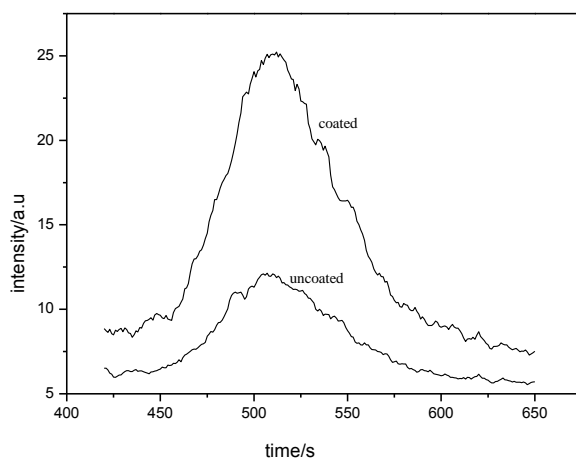


Fig.4 Emission spectrum of phosphors before and after SiO_2 coating in the composite coatings

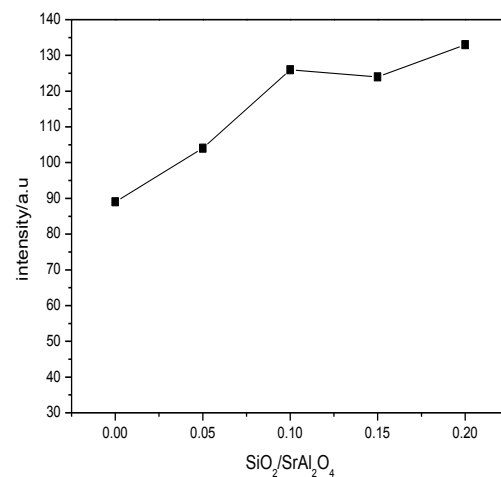


Fig.5 Emission intensity of composite coatings with different coated ratio of SiO_2

Fig.4 shows Emission spectra of coated and uncoated $\text{SrAl}_2\text{O}_4:\text{Eu}^{2+},\text{Dy}^{3+}$ phosphors after supersonic plasma spray. The emission spectra exhibit a broad band peaking at 505nm which is attributed to the emission of Eu^{2+} ions with $4f^65d-4f^7$ (8s) transition and the intensity of $\text{SrAl}_2\text{O}_4:\text{Eu}^{2+},\text{Dy}^{3+}$ after SiO_2 coating is stronger than that of un-coating, which indicated quenching of

$\text{SrAl}_2\text{O}_4:\text{Eu}^{2+},\text{Dy}^{3+}$ were efficiently avoided after SiO_2 coating. This is because of SiO_2 coating showed good high temperature resistance on the surface of phosphor and segregate the phosphors from the metal ions, which can quench the luminescence. As showed in Fig.5, the luminescent intensity shows a maximum when the mass ratio of SiO_2 is 10%.

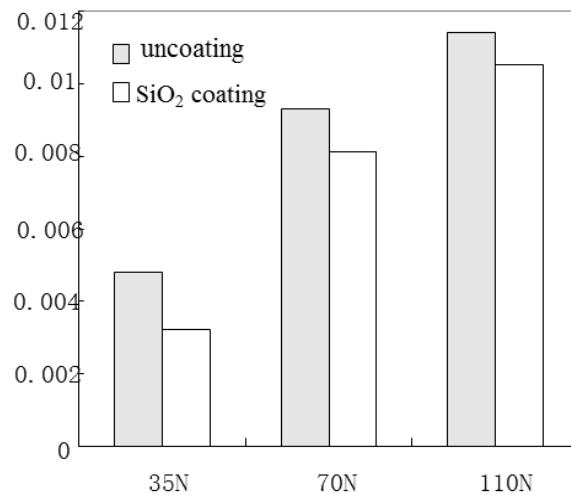


Fig.6 The wear loss of the composite coating coatings with different coated ratio of SiO_2

The wear loss of composite coatings comprised with Cu-14Al-X / $\text{SrAl}_2\text{O}_4:\text{Eu}^{2+},\text{Dy}^{3+}$ before and after SiO_2 coating have been recorded in Fig.6. Under the test loads of 35N, 70N, 110N, the composite coating after SiO_2 coating shows the lower wear loss than un-coating which means good anti-friction and anti-wear property. The reason is that SiO_2 coating can not only contribute high hardness to the $\text{SrAl}_2\text{O}_4:\text{Eu}^{2+},\text{Dy}^{3+}$ particles but also deposit in boundary film play the role of self-replenish in the worn surface. The SiO_2 coating behaves like a self-lubricant between pin and substrate, which could repair the wear surface. It is known that as a solid lubricant, the crystal structure of SiO_2 films is hexagonal layered and the mechanism behind their effective lubricating performance is attributed to easy shearing of the hexagonal crystalline structures [7].

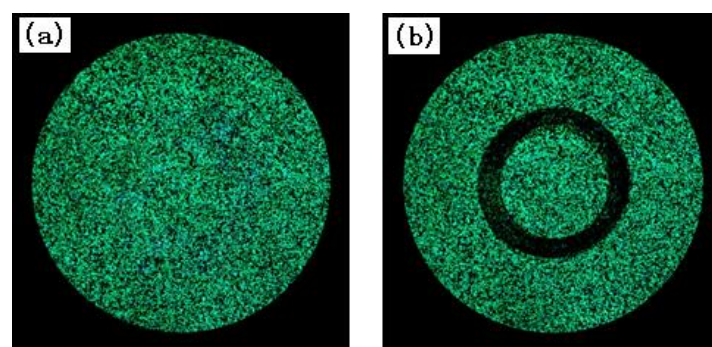


Fig. 7 Morphology of the Phosphorescent composite coatings before and after wear test

(a) Coatings before wear; (b) coatings after wear

The surface of the coating was observed under UV light before and after the wear test (Fig 7a and Fig7 b). The wear test time of the coating is 2800s. Compared with the unworn coating (Fig 7 a), the wear track is clearly visible as black circles. This demonstrates that the damage caused during wear test can be clearly observed under UV light. When the light disappeared, it indicates the coating wearied off and the substrate exposed, so the composite coating is expected as luminescence function coating for monitor wear.

4. Conclusion

The results shows that, thermal quenching of $\text{SrAl}_2\text{O}_4:\text{Eu}^{2+},\text{Dy}^{3+}$ were efficiently avoided after SiO_2 coting and the luminescent intensity shows a maximum when the mass ratio of SiO_2 is 10%. $\text{Cu-14Al-X} / \text{SrAl}_2\text{O}_4:\text{Eu}^{2+},\text{Dy}^{3+}$ composite coating doped with SiO_2 coating shows not only the good luminescence function for monitor wear but also good anti-friction and anti-wear property. Also, SiO_2 coating as additive could repair the wear surface in the wear process that can increase anti wear ability and load-carrying capacity of composite coatings.

Acknowledgements: National Natural Science Foundation of China (51674130) and The International Science and Technology Cooperation Projects (2015DFR51090) supported this research.

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