

Influence of emissivity on laser-induced damage of low absorption thermal Control coatings

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Abstract. In order to evaluate the performance of the low absorption thermal Control coatings, the laser induced damage behavior of coatings was studied with 1064 nm at different power densities. The damage properties were characterized by scanning electron microscope (SEM) and X-ray diffraction spectrum. The results show that the specimens of both A-1 and A-2 can be damaged by the laser. Combined with the temperature effect, the effect of infrared emissivity of the coating to the damage behavior of the two specimens is mainly due to the temperature effect by infrared emissivity and stacked structure.

Keywords: emissivity;laser-induced damage;low absorption;thermal control coating

1. Introduction

Thermal control coatings are an important method to maintain the steady-state temperature for spacecraft [1, 2]. However, with the development of high energy, or high peak power laser system, it is always a problem for the coating to be damaged-cracked, melted or exploded, which will lead to a fatal blow for on-orbit satellite [3, 4]. Many interests have been made to investigate the process and mechanisms of laser induced damage of materials and coatings [5-9]. The damage process that is consistent with the observations as a function of laser power density and irradiation time is related to thermal effect [7]. Thermal accumulation becomes prominent as the RR(repetition rate) exceeds 10 kHz and becomes a main factor in the damage when the RR is more than 100 kHz[8]. Under sub-damage threshold irradiation, conductivity and reflectance of the ITO films were maintained without measurable degradation. The ordered mesoporous coating with a fiber-like skeleton led to the minimum damage of the substrate. Some other investigations were focused on the coating properties. The laser damage properties were also affected by the coating preparation parameters and its thickness, coating materials, third harmonic generating element and so on.

In this work, the damage performance of low absorption thermal Control coatings induced by the fundamental 1064nm high repetition rate laser was studied. The influence of laser power and coating emissivity was discussed and the heat effect mechanism of the laser was studied.

2. Experimental

2.1 Specimens preparation

Experiments were conducted on the 5A06 aluminum specimens with thermal coatings of A-1 and A-2 with solar absorption ratio to 0.20. The specimen was cut into 40mm×40mm and then painted by the thermal control coatings. The coating thickness was 120±5um.

2.2 Laser damage tests

Laser damage experiments were carried out using high-repetition rate Nd:YAG laser with wavelength 1064nm. The spot diameter on the target plane was 10mm×10mm. The specimens were held vertically with the film facing the laser. The temperature sensor was pasted at the back of the specimen.

2.3 Damage characterizations

After tests, the morphologies were characterized by optical camera (OC) and scanning electron microscope (SEM). The Element change were characterized by using Energy Dispersive Spectrometer (EDS). The damage area was calculated by dichotomy area measurement method.

3. Results and Discussion

3.1 Morphologies analyses of the coatings

The macro morphology of the coatings after laser damage by different power density were shown in Fig1. It can be seen that there are no visible damages of both of the specimens at 500W/cm². After 1000 W/cm² laser continuous ablation for 5 seconds, the A-1 coating remains undamaged and the structure has no change, but the surface of specimens A-2 becomes to black burnt morphology.

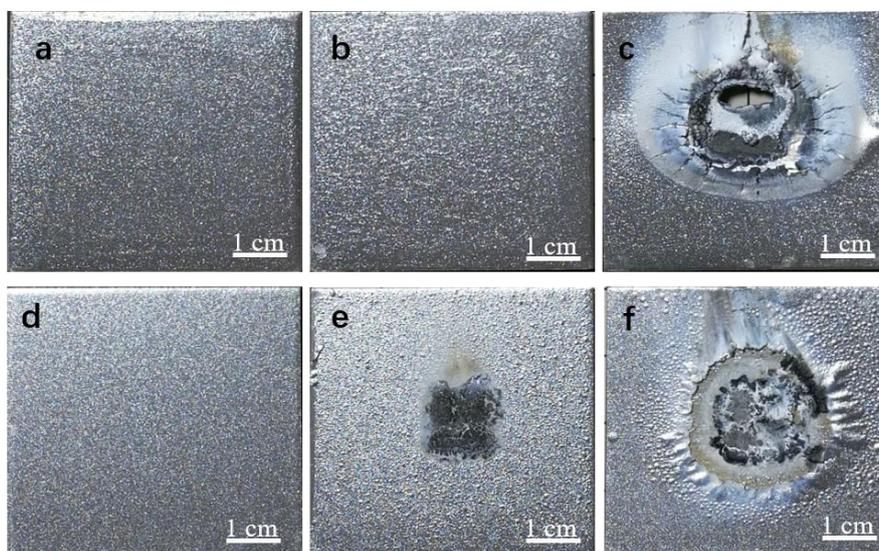


Figure 1. OC morphologies of the coatings after laser tests
(A-1: a: 500W/cm², 5s; b: 1000W/cm², 5s; c: 1500W/cm², 10s; A-2: d: 500W/cm², 5s; e: 1000W/cm², 5s; f: 1500W/cm², 1s)

After 1500 W/cm² laser continuous affect for 2 seconds, the A-1 coating starts burning, and part of the substrate is ablated, melted and perforated. The cracks appear on the surface of the coating in the ablated area, which diverged along the perforation. The specimen is warped and deformed. While the power density increases to 1500 W/cm² for 10 seconds, the ablated area of the A-1 coating becomes black, with bubble-like structure, forming a larger ablation pore than the spot area. The edge of the pore shows divergent crack morphology, alleviated the thermal expansion.

The A-2 coating is ablated off by 1500 W/cm² laser from 1 second, the coating in the ablated area is completely broken down and burned to black. In addition, large bubbling areas appear in the non-ablation zone. Part of the coating burns and swells into a volcanic shape. The metal substrate also exhibits serious damage.

The micro morphologies of the coatings are shown as Fig.2, and the EDS results are given in table1. It can be seen that the Al content of A-1 is higher than that of A-2, which shows filler stacked morphology in A-1 and melt embedded morphology in A-2. After laser damage test, all the damage specimens present burning morphologies. The increase of oxygen content indicates that the oxidation reaction has mainly occurred.

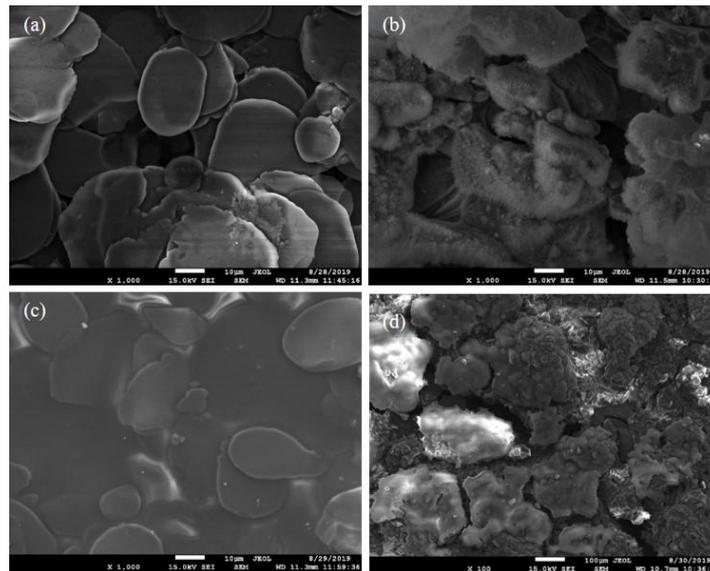


Figure2. SEM morphologies of the coatings before (a A1, c, A2) and after (b, A-1 1000W/5s, d, A-2, 1500W/2s) laser tests

Element(Weight%)	A-1		A-2	
	Before test	After test	Before test	After test
C	10.28	10.72	21.32	4.54
O	15.05	33.20	21.21	53.11
Al	58.98	55.57	36.95	10.50
Si	15.68	0.50	20.52	31.85

Table 1. Element contents before and after laser damage tests

The XRD results of the specimens before and after tests(1500W/2s) are shown in Fig.3. It can be seen that the samples of A-1 and A-2 before and after the experiment are mainly composed of Al and Al₂O₃. Compared with before the experiment, the content of Al₂O₃ after damage increases, indicating that the local Al is thermally oxidized, which is different from EDS. The results are consistent with the EDS.

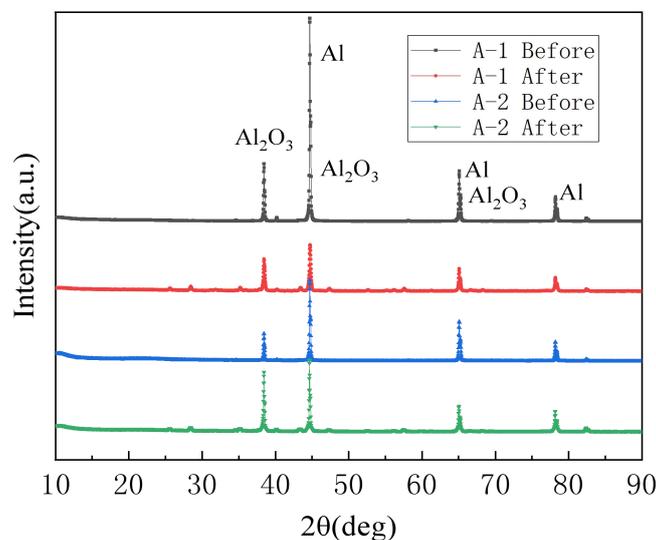


Figure3. The XRD results before and after tests

3.2 Damage area analyses of the coatings

The damage area analysis results after tests are shown in table 2. The specimen of A-1 is damaged after 1500W/cm² laser continuous ablation for 2 seconds, the damage area was 1.31 cm², and the coating is not broken down. In the continuous ablation of 1000W/cm² laser for 5 seconds, the A-2 coating is damaged. The damage area is 1.18 cm², and the coating is not broken down. At the same power of 1500 W/cm² for 2s, the specimen of A-1 shows smaller damage area, but deeper damage, even to the substrate, which shows that the heat of the A-1 sample is more concentrated.

Table 2 Damage area of the coatings

Specimen	Power(W/cm ²)	Time(s)	Damage area of coating (cm ²)	Blade off area of coating (cm ²)	Blade off area of substrate (cm ²)
A-1	500	5	/	/	/
	1000	5	/	/	/
	1000	10	/	/	/
	1500	2	1.31	1.31	0.05
	1500	5	8.95	1.43	0.20
A-2	500	5	/	/	/
	500	10	/	/	/
	1000	5	1.18	/	/
	1500	2	9.24	3.06	/

3.3 Discussion

The laser induced damage is mainly caused by heat effect on the coating surface[8]. In order to find out the failure mechanism of the two specimens, the temperature was in situ monitored. The temperature curves with time of the two specimens are shown in Fig.4. The temperature is 1483 °C of the A-1 specimen after 1500W laser damage for 5s, while 641 °C of the A-2 specimens, respectively. Under the same power density, the temperature of the A-1 sample is significantly higher than that of the A-2 sample. And with the increase of the laser intensity, the temperature of the A-1 sample increases more significantly. It indicates that the heat dissipation effect of sample A-1 is worse, which leads to temperature concentration and more obvious longitudinal damage, consisted with the results of SEM morphology and damage area.

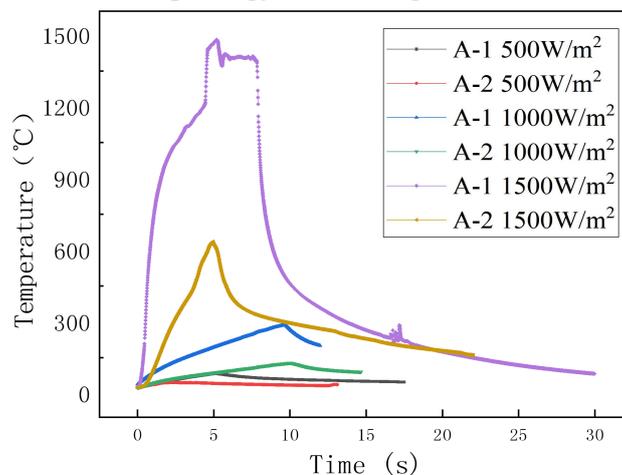


Figure4. Temperature change of the specimens in laser damage test

The Infrared emissivity of the specimens at different laser power density is given in Fig.5, while the reflectance of the specimen before and after tests (1500w/2s) is shown in Fig.6. It can be seen that the infrared emissivity of the A-2 sample before the test is 0.4, while the A-1 sample is 0.21. Before and after all the tests, the infrared emissivity of A-2 is higher than that of A -1. But the

reflectivity of A-1 and A-2 drops slightly after the laser damage test, which is mainly due to the damage to the sample surface. The emissivity of the two samples has the same value both before and after the test. It suggests that high infrared emissivity is the main reason that affects laser damage behavior.

Combined with the temperature effect, the damage behavior of the two specimens is mainly due to the temperature effect by infrared emissivity and stacked structure. The high infrared emissivity can promote heat dissipation in the air, thereby effectively reducing the surface temperature and protecting the coating from laser damage. The layered structure of the A-1 sample limits the thermal diffusion, and the longitudinal thermal damage is obvious. The fusion structure of the A-2 sample can effectively inhibit the longitudinal heat transmission, and more of the plane diffusion heat, so the heat dissipation effect is significantly better than that of A-1 sample, thus the temperature is lower than A-1 sample.

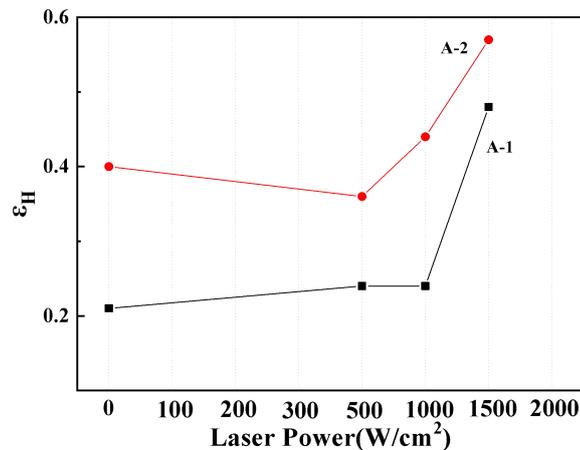


Figure5. Infrared emissivity of the specimens before and after test

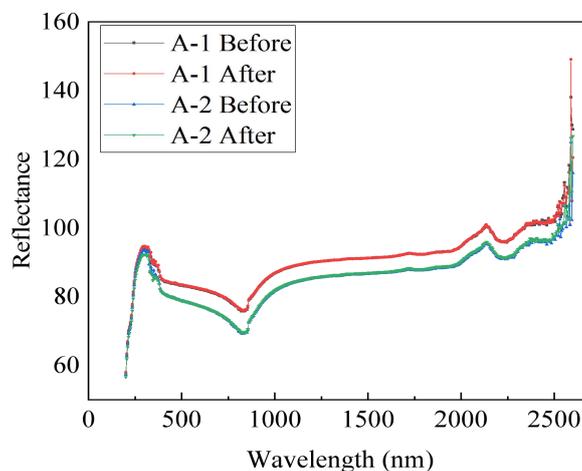


Figure6. The reflectance of the specimen before and after (1500w/2s) tests

4. Conclusion

The laser induced damage behavior of low absorption thermal Control coatings was studied with 1064 nm at different power densities and it can be concluded that:

(1) The specimens of both A-1 and A-2 can be damaged by the laser, mainly thermal oxidation of aluminum. While A-1 sample has obvious depth damage, while the A-2 sample surface peels more obviously.

(2) The infrared emissivity of the A-1 sample is 0.21, which lead to that the temperature achieve 1483°C after 1500W laser damage for 5s, while only 641°C for the A-2 specimens because of the infrared emissivity of 0.4, respectively.

(3) The effect of infrared emissivity of the coating to the damage behavior of the low absorption thermal Control coatings is mainly due to the temperature effect caused by infrared emissivity and stacked structure.

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