Research on Design and Performance of Optic-thermal Coupling Effect Evaluation System for Aerospace Material

Wang Junwei1,*, Zhang Lei1*, Zhang Pengsong1 and Bai Bing1
1Beijing Institute of Spacecraft Environmental Engineering, Beijing 100094, China
*always@nuaa.edu.cn
*tobenol@126.com

Abstract. The optic-thermal coupling effect evaluation system for aerospace materials is mainly used to simulate the environment of solar radiation with different intensities in a constant-pressure and temperature-varying environment to test the photochemical effect and optic-thermal effect tolerance of aerospace materials. This paper introduces the key design and numerical simulation results of the system. The results show that the temperature and radiation intensity range of system is sufficient to meet the test requirements of the national military standard. The deviation between the temperature setting value and the measured value is within 0.5℃, and the light deviation is less than 5%.

1. Introduction
Solar radiation has serious effects on materials, including thermal and photochemical effects, which can seriously affect the life of material. In order to demonstrate thermal and photochemical effects caused by solar radiation on mechanical and electrical properties of aerospace materials and mechanical products, it is necessary to verify the environmental adaptability through solar radiation evaluation tests. The optic-thermal coupling effect evaluation system for aerospace materials is mainly used to simulate the solar radiation environment with different intensity in the atmospheric pressure and variable temperature environment to test the photochemical effect and optic-thermal effect tolerance of aerospace materials.

The artificial light is used to simulate the whole spectrum solar optic-thermal coupling effect. The reference standard is different according to the different research purposes[1-2]. The test purpose of GB/T 2423.24 2013 "Environmental testing-Part 2: Test method-Test Sa: Simulated solar radiation at ground level and the guidance for solar radiation testing" is to examine the thermal, mechanical, chemical, electrical effect and adaptability of electrical products and materials under solar radiation on ground. The standard requires that the simulated light source should have an irradiance of 1120± 10% W/m² on the specified irradiance plane of the simulated system. It also requires that the simulated system can maintain the specified temperature and humidity, and the airflow velocity should be adjustable within the range of 0.1~0.5m/s[3]. The purpose of the GJB 150.7A-2009 is to evaluate the thermal and photochemical effects of military equipment used and stored outdoors without shade[4]. The standard includes two test procedures: cyclic heat effect and steady-state long-term photochemical effect, both of which require the total radiation intensity in the simulated equipment to reach 1120± 10% W/m².
2. Overall design of system
The optic-thermal coupling effect evaluation system for aerospace material mainly consists of temperature subsystem and radiation subsystem. The temperature subsystem is designed according to technical requirements, whose temperature range, rate of rise and fall, deviation, fluctuation, uniformity meet all the cycles of the national military standard GJB 150. The radiation subsystem consists of multiple xenon lamps and is equipped with cooling system, which can ensure the light intensity and uniformity of the various gears required by the evaluation system.

2.1. The temperature subsystem
The temperature subsystem is mainly composed of the structure unit, refrigeration unit, heating unit, humidification unit, dehumidification unit and control unit. The core component is the refrigeration unit, which directly determines the cooling rate and extreme low temperature of the system. The inner structure of the system adopts AISI-304 stainless steel plate, and corner bending argon arc welding is used to ensure that there are no welding points in the effective space. The whole system is sealed to prevent moisture from entering the internal working space. During the temperature rise and fall, all seams and corners can withstand thermal expansion and contraction. The exterior of the system is a high-load-bearing welded steel structural frame, which is covered with a metal cover. The inside and the cover are covered with seals and insulation layers to prevent ambient gases and moisture from entering the insulation layer during low temperature operation.

The system adopts a double-layer material structure for heat preservation. The inner layer is made of non-deposited glass fiber, which has the characteristics of low "K" value, non-flammable, non-deposited, and low thermal conductivity. The outer layer of glass fiber is entirely sealed with aluminum foil to prevent moisture from entering fiber material. The outer layer is made of polyurethane flame-retardant board with a density of ≥ 40kg/m³, which can strengthen the overall strength of the system.

The observation window of the system is composed of 4 pieces of tempered glass. The gap is vacuum-treated to reduce the heat conduction of the observation window. The inside and outside of the observation window are equipped with heating films to prevent the system from condensation while it's running at low temperature or humidity. Insulation seals are installed inside and outside the observation window to prevent gas from entering the door.

Refrigeration system includes oil separator, air-cooled condenser, drying filter, main refrigeration solenoid valve, main refrigeration thermal expansion valve, hot gas bypass solenoid valve, thermal injection system, evaporator, suction pressure stabilization pipe and scroll compressor. The refrigeration processes are shown in Figure 1.

Figure 1. The flow chart of refrigeration system
2.2. The radiation subsystem

As shown in Figure 2, the radiation subsystem adopts a symmetrical structure placed on the top of the system, and the irradiation area is not less than 800×800mm. Its structure mainly includes light source, reflector, power supply, heat sink, recording device of radiation intensity. The maximum radiant energy is 1120W/m², which is adjustable at 1120 W/m², 840 W/m², 560 W/m², 280 W/m². There are a total of four sets of units. The width of each unit is 1040×1040mm, which is symmetrically arranged. The lamp unit is connected with the temperature subsystem through a connection plate, and the light is radiated into the system through the ultraviolet quartz glass.

Figure 2. Schematic layout of the lamps array

The circuit design adopts trigger interference isolation, the trigger and other structures are isolated by PTFE board, high-voltage resistant wires are used, and the internal circuits are protected by silicone tubes. The binding posts use copper binding posts to avoid UHV breakdown. The outer layer is protected by a polytetrafluoroethylene sleeve to avoid high voltage discharge caused by the xenon lamp. The protection of lamps array is shown in Figure 3.

Figure 3. Protection of lamps array

The reflector is a round symmetrical wide-illumination lamp reflector. The whole is made of aluminum alloy. The surface is sandblasted and oxidized. The thickness is 3mm-4mm. There is an electrode mounting hole in the middle to make the light source horizontal. The light distribution design of reflector is shown in Figure 4.
3. Numerical simulation of the system

3.1. Simulation results of lamps array
As shown in Figure 5 and 6, the irradiation simulation adopts a model of 1000×1000×1200 (L×W×H). Four sets of 1600w xenon light sources are set at 1.2 meters from the bottom surface. A calculation surface of 1.0×1.0m calculation surface is set at 1.2 meters from the xenon lamp. A calculation surface of 0.8×0.8m is set at 1.1 meters and 1.0 meters, respectively. The uniformity finally achieved by the lamp array system is 0.743, and the average irradiance value reaches 1.89lx.
3.2. Simulation results of optic-thermal coupling field

The turbulence model was a Relizable k-ε model, and the DO model was selected for radiative heat transfer. The inlet adopts speed inlet boundary conditions, and the air temperature is divided into three working conditions: 20℃, 50℃, and 70℃. The radiant heat transfer power of the lamp array to the system is 3000W. Heat flux boundary conditions are selected. The figure 7 shows the simulation results of the optic-thermal coupling temperature field under the conditions of 20℃, 50℃, and 70℃. It can be seen that the temperature field is evenly distributed under the three working conditions in the system and is close to the inlet temperature of the system. Due to the influence of heat leakage, the wall of system is close to the ambient temperature, and it is more obvious at the top because there is no insulation layer, which is in line with theory and expectations.

4. The testing results

The test was carried out using the procedures of GJB150.7A-2009. The test system meets the following requirements: a) the air temperature of the system is adjusted to the minimum value of the temperature cycle without irradiation; b) the control of irradiance and temperature is shown in Figure 8: the maximum radiant energy of the light is 1120 W/m², which can be divided into 1120 W/m², 840 W/m², 560 W/m², 280 W/m². The temperature and radiation per hour is shown in Table 1 and Figure 8. The specific testing results are shown in Figure 9.

| No. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|-----|---|---|---|---|---|---|---|---|---|
| T (℃) | 37 | 35 | 34 | 34 | 33 | 33 | 32 | 32.5 | 33 |
| L(W/m²) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 280 |
| Time(min) | 0 | 60 | 60 | 60 | 60 | 60 | 60 | 30 | 30 |
| No. | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| No. | T (℃) | 35 | 38 | 41 | 43 | 44 | 47 | 48 | 48 | 49 |
|-----|-------|----|----|----|----|----|----|----|----|----|
| L(W/m²) | 560 | 840 | 840 | 1120 | 1120 | 1120 | 1120 | 840 | 840 | |
| Time(min) | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | |

| No. | T (℃) | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|-----|-------|----|----|----|----|----|----|----|----|----|
| L(W/m²) | 560 | 280 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Time(min) | 60 | 30 | 30 | 60 | 60 | 60 | 60 | 60 | 60 | |

The debugging results show that the range of temperature and radiation intensity of the system is sufficient to complete the test profile in GJB150.7A-2009. The variation of the temperature and light of the day can be simulated according to the requirements of the national military standard. The deviation between the temperature setting value and the measured value is within 0.5℃. The measured value in the 1120W/m² range is 1170±5 W/m² with a deviation of 4.5%, and the measured value in the 840 W/m² range is 870±5 W/m² with a deviation of 3.6%, all less than ±10%.
5. Conclusion
The solar radiation test for aerospace materials can truly show the suitability of materials for storage, transportation, and use under environmental conditions of solar radiation. This paper introduces the key design and numerical simulation results of the optic-thermal coupling effect evaluation system. The results show that the temperature and radiation intensity range of system are sufficient to meet the test requirements of the national military standard, which provide a reference for the subsequent development of testing and facility.

References
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