Used For Space Irradiation Environment Simulation Equipment Property Analysis of Metal Mirror

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Abstract. With the development of space science and technology, the requirements of spacecraft environment simulation tests are gradually increasing, and radiation environment simulation has also attracted much attention. Based on space radiation environment simulation equipment of vertical metal reflector material in the solar simulator performance analysis, the systematic analysis of the influence factors of metal reflector, aimed at straight metal mirror blank material performance analysis, including the mechanics analysis and optical analysis, the performance to the blank material for testing. The test results show that the aluminum alloy 6061T6 billet used in the metal mirror can meet the requirements of high irradiation vertical solar simulator, and lay a solid foundation for the subsequent solar irradiation simulation, space illumination simulation and spacecraft thermal environment simulation.

Keywords: Aluminum 6061, Metal mirror, Performance analysis, Vertical solar simulator, Aerospace.

1. Introduction

With the development of space science and technology, the demand for spacecraft environment simulation is increasing day by day. The environment simulation mainly includes lighting environment, thermal environment, vacuum environment and low temperature environment simulation. Among them, the illumination environment simulation is mainly used for satellite thermal balance test [1-3], which can simulate the illumination situation of the satellite [4-6] and verify the thermal design of the satellite to improve its reliability. The ground illumination simulation is mainly carried out through the solar simulator. Off-axis vertical solar simulators have been studied in foreign countries in the early stage. Most of the existing large and medium-sized off-axis solar simulators in China adopt horizontal structure. Vertical solar simulators have advantages such as space saving and high performance, etc., and have gradually attracted attention. Solar simulator mainly includes light source, integrator, window mirror and collimation mirror [7-9]. Among them, the collimating lens system as the final output element, has to modify system simulation before the sun beam, collimating and transfer function [10-12], its structure of nickel plating aluminum alloy metal reflector, for collimating lens is total energy output mechanism, so the mirror surface will be under the high thermal energy load,
and the need to avoid high quantity of heat caused by structure deformation. Therefore, the structural stability of the metal mirror substrate material is required to be higher.

This paper analyzes the performance of the collimating metal mirror material in the vertical solar simulator, a simulation equipment for space irradiation environment. Due to the high irradiation energy of the vertical solar simulator, the surface energy of the collimating mirror is concentrated, and the structure is prone to deformation and fracture, which requires a high level of metal mirror material. In this paper, the optical and mechanical analysis of the metal mirror material and structure in the vertical solar simulator is carried out to improve the structural stability so as to improve the irradiation uniformity, irradiance and other optical properties of the solar simulator.

2. Highly irradiated vertical solar simulator for aerospace applications

The solar simulator designed in this paper adopts a vertical mechanism, which is composed of xenon lamp, integrator, window, collimator and support mechanism. The maximum irradiance shall be 2 solar constants (i.e., 2706 W/m²), the diameter of the irradiation surface shall be 1000 mm, the irradiance non-uniformity shall be ±5%, the off-axis Angle of the system shall be 39°, and the collimation right Angle shall be less than ±2°. The structural diagram of the vertical solar simulator is shown in Figure 1.

In the solar simulator, the main function of the collimating metal reflector is to generate parallel beams to ensure that the beams are irradiated uniformly along the optical axis in a certain depth, and its focus coincides with that of the projection mirror of the integrator. The aperture of the collimating mirror designed for the solar simulator is 1600 mm and the radius of curvature is 8890 mm. In this metal mirror, a whole piece of T6061-T6 aluminum alloy material is used, and the surface is treated with nickel plating, polishing and coating, as shown in Figure 2.

![Fig. 1 Structure diagram of vertical solar simulator](image1)

![Fig. 2 General diagram of collimator mechanism](image2)
3. Performance analysis of metal mirror of high irradiated vertical solar simulator

The vertical solar simulator's collimator assembly is designed with a vertical hanging structure, in which the collimator unit is fixed by 4 points and 14 points of elastic steel rope to form an integral fixed connection. This structure can make the unit mirror mainly affected by its own gravity, and the external stress environment is relatively simple, so the mechanical properties of materials are not particularly high. Here, according to the structural characteristics of the high-irradiation solar simulator, combined with the material characteristics and technological impact of the collimating metal mirror, the influence of processing technology on the performance of the collimating mirror unit is analyzed.

The key points in the table of important material properties that affect the performance of metal reflectors in the design and installation of metal reflectors in the design and installation of optical mechanical systems by Paul R. Yoder, Jr.

The mechanical properties and metallurgical properties should be considered in view of the use of sheet clinker in the collimator. Other, physical properties, optical properties, machining properties of the project cannot be considered.

3.1. Effect of billet processing technology on mechanical properties of materials

According to the material certificate provided by the blank manufacturer, it has been pre-stretched. In the transverse direction of the sheet rolling, its yield strength is 305MPa, tensile strength is 335MPa and elongation index is 11.1%, which is much higher than the requirements of the American standard AMS4027. And the transverse direction is the weakest direction of the plate structure, which is higher than the standard, as shown in Table 1.

| Tab. 1 Tensile Test Results of Unit Mirror Plate |
|------------------------------------------------|
| Tensile stress at yield (offset 0.2 %) | Tensile stress in tensile strength |
| (MPa) | (MPa) |
| 1 | 305 | 335 |
| 2 | 306 | 337 |
| 3 | 308 | 339 |

3.2. Effect of billet processing technology on metallurgical properties of materials

Sheet metal blank processing is divided into forging and rolling two processes, because of different processes, there may be different degrees of influence on the use of materials, in this paper for the forging and rolling two processes on the use of metal mirror performance is analyzed.

3.2.1. The difference between forging and rolling processes. Casting, forging, machining and some heat treatment processes can increase the residual stress in the mirror substrate. Therefore, stress relief is required for any substrate during processing, usually by heat treatment. Toland et al. described experiments with forged aluminum 6061-T651 and compared these results with those obtained by Ohl et al. with a blank sheet material of the same material, concluding that if different classes of blank materials are used and a similar heat treatment process is used, a mirror with similar optical properties will be formed [13]. Therefore, as long as the forged blank and the rolled blank adopt the same heat treatment process, the mirrors with similar optical properties can be obtained.

3.2.2. Follow-up heat treatment of billet. Aluminium and aluminium alloy is light weight, strong, and economic easy molding material, widely used in optical instrument parts and structure, through the investigation and research, many scholars at home and abroad for the material of aluminum alloy presents a typical thermal cycle process data, and provides the corresponding method, through the heat treatment process can eliminate aluminum reflector in the low temperature stress. Collimation type metal reflector is usually 3 times thermal cycling treatment, three cold circulation processing, a total of six times circulation, including 1 unit mirror blank prior to the factory for heat treatment, mechanical
rough machining for 1 time before heat treatment, mechanical semi-finishing 1 time before heat treatment, mechanical finishing in front of three cold circulation processing.

4. Simulation analysis of metal mirror

Here, on the straight metal reflector mechanics simulation, USES the manufacturer to provide mechanical data, through the finite element software ANSYS is analyzed with mechanics, and the software come with warehouse, warehouse at the beginning of analysis of aluminum alloy, the elastic modulus of 71 gpa, actual use of aluminum alloy material and ANSYS software in the warehouse the mechanical properties of aluminum alloy. The whole collimating mirror (including the rear mechanical structure) was simulated and analyzed. The collimating mirror was subjected to the action of gravity to simulate the real use state, and the force analysis was carried out. The following results were obtained: PV value of mirror deformation after collimating mirror fitting was 9.3μm, and its maximum stress was 34MPa. According to the above simulation analysis results, further optical simulation analysis shows that the irradiation uniformity of the solar simulator can reach ±3.93%, meeting the indicator requirement of ±5% of the overall optical performance. See Fig. 3 for details.

![Mechanical Analysis Results](image1) ![Optical Analysis Results](image2)

**Fig. 3** Simulation Analysis of Collimator Assembly

5. Metal mirror material performance testing

In order to further determine the performance state of the collimating metal mirror material, the material is analyzed and tested here. Testing the sample of the material from the metal reflector formally parts of the same piece of blank material more than expected, the test items include elastic modulus and stress, direction of test samples selected randomly, there were a total of 6 pieces of elastic modulus of samples, including three pieces of handle state, for not to stress three pieces for after dealing with the stress elimination of state, the size of the samples as shown in figure 4.

![Sample of Elastic Modulus of Aluminum Alloy Sheet](image3)

**Fig. 4** Sample of Elastic Modulus of Aluminum Alloy Sheet
5.1. Elastic modulus test
Under the condition of no stress relief treatment, the average elastic modulus of the sample is 72.6 GPa, and there is only a 1.6 GPa error between it and the theoretical value of 71 GPa, and the relative error is 2.3%, as shown in Table 2. Among them, sample No.1 has a large difference from the average value, with a standard variance of 0.17 GPa, which may be the result of the combined effect of measurement error and machining stress.

| Modulus of elasticity (MPa) | The tensile stress is yielding (MPa) | Tensile stress in tensile strength (MPa) |
|-----------------------------|--------------------------------------|----------------------------------------|
| 1                           | 70687.15845                         | 290.08416                               | 312.98190                           |
| 2                           | 73885.04450                         | 290.33639                               | 316.15735                           |
| 3                           | 73260.59317                         | 288.10816                               | 313.60770                           |
| Average                     | 72610.93204                         | 289.50957                               | 313.58232                           |
| The maximum                 | 73885.04450                         | 290.33639                               | 316.15735                           |
| The standard variance       | 1695.041                            | 1.220                                   | 2.333                                |

Under the stress reduction condition, the average elastic modulus of the sample is 71.5 GPa, which has only 0.5 GPa error with the theoretical value of 71 GPa, and the relative error is 0.7%. The standard variance is only 0.04 GPa, and the elastic modulus is very consistent, as shown in Table 3.

| Modulus of elasticity (MPa) | The tensile stress is yielding (MPa) | Tensile stress in tensile strength (MPa) |
|-----------------------------|--------------------------------------|----------------------------------------|
| 1                           | 71200.61587                         | 245.32848                               | 271.38934                           |
| 2                           | 71332.88172                         | 292.68165                               | 314.60806                           |
| 3                           | 71926.88505                         | 290.74312                               | 313.48392                           |
| Average                     | 71486.79421                         | 276.25108                               | 299.82711                           |
| The maximum                 | 71926.88505                         | 292.68165                               | 314.60806                           |
| The standard variance       | 386.825                             | 26.797                                  | 24.634                               |

5.2. Internal stress detection
Through the elastic modulus test of the sample, it can be seen that the elastic modulus of the collimating mirror material is basically consistent with the theoretical value. The internal stress of the sample was detected by X-ray diffractometer. X, Y and Z represent three batches of internal stress samples respectively. The A direction is the machining direction, and the B direction is perpendicular to the A direction. The test results are shown in Table 4.
Tab. 4 Internal Stress Test Results of The Sample

| Number | An internal stress (MPa) | B internal stress (MPa) |
|--------|--------------------------|-------------------------|
| The sample X |                          |                         |
| 1      | 50.4                     | 4.1                     |
| 2      | -2.9                     | 42.3                    |
| 3      | 33.2                     | 109.8                   |
| Average| 26.9                     | 52.1                    |
| The sample Y |                          |                         |
| 1      | 46                       | 9.1                     |
| 2      | -11.5                    | 125.2                   |
| 3      | 3.5                      | 18.1                    |
| Average| 12.7                     | 50.8                    |
| The sample Z |                          |                         |
| 1      | 11.4                     | 86.8                    |
| 2      | -27.6                    | 2.5                     |
| 3      | -14.9                    | 98.4                    |
| Average| -10.4                    | 62.6                    |

According to the detection results, there is no significant difference in the orientation of the three samples. The analysis of the detection results of the orientation of the single sample shows that the internal stress is not necessarily related to the machining direction, and the maximum internal stress may be generated in both A and B directions. In addition, the average value of the internal stress is related to the machining direction, and the internal stress is larger in the B direction, about 50-60 MPa. The internal stress of 50-60 MPa relative to the theoretical elastic modulus of the aluminum alloy sheet 71GPa can be considered to have eliminated most of the internal stress, and will not affect the collimation mirror shape accuracy.

6. Conclusion
In this paper, the factors affecting the performance of metal reflectors were systematically analyzed. According to the structural characteristics of the vertical solar simulator, the performance of the raw material of the vertical hanging collimating metal reflector was analyzed, including mechanical analysis and optical analysis. Finally, the performance of the raw material was tested. The aluminum alloy 6061T6 billet used in the metal reflector can meet the requirements of high irradiation vertical solar simulator. In addition metal mirror blank material structural stability directly affect the machining after jiang, in use process must keep straight metal reflection mirror surface shape accuracy, therefore in the subsequent processing can be used many times in the process of surface shape accuracy of the measurement method to verify the stability of the structure of metal reflector, especially for many times in the process of polishing surface shape detection, mastering the mirror surface form, Ensure the mirror polishing to meet the requirements. The metal mirror materials analyzed in this paper can be used in common solar simulator equipment with different structures, laying a solid foundation for the subsequent solar irradiation simulation, space illumination simulation and spacecraft thermal environment simulation.

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