Thin-Walled Structures 85 (2014) 15–24

Contents lists available at ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

Study on the thermal behavior of aluminum reticulated shell structures considering solar radiation

Hongbo Liu [a,b,c], Zhihua Chen [a,b,c], Qinghua Han [b,c,*], Binbin Chen [b], Yidu Bu [b]

[a] State Key Laboratory of Hydraulic Engineering Simulation and Safety, Tianjin University, Tianjin 300072, China
[b] Department of Civil Engineering, Tianjin University, Tianjin 300072, China
[c] Tianjin Key Laboratory of Civil Engineering Structure & New Materials, Tianjin University, Tianjin 300072, China

ARTICLE INFO

Article history:
Received 19 September 2013
Received in revised form
16 March 2014
Accepted 11 July 2014
Available online 23 August 2014

Keywords:
Aluminum dome
Solar radiation absorption coefficient
Non-uniform temperature
Thermal behavior

ABSTRACT

The aluminum dome has been more and more widely adopted in industrial and civil buildings, and the span is up to 140 m. Because the thermal expansion coefficient of aluminum with a value of 2.3×10^{-5} is almost two times than that of steel, the temperature change will induce significant thermal deformation and thermal stress, especially for the large span aluminum domes under solar radiation. In this paper, the solar radiation absorption coefficient was firstly measured using spectrophotometer, and then a numerical simulation method was presented and verified by test dada. To take a aluminum dome project with a span of 125 m for an example, the non-uniform temperature distribution and change under solar radiation were analyzed using the presented method, and following conclusions were obtained: (1) The thermal load is the key load for the aluminum domes, and the solar radiation has a significant effect on the thermal behavior of the aluminum domes. Therefore, the non-uniform thermal load considering solar radiation has to be considered in the future design. (2) There is a remarkable variation of member stress, and it is necessary to study the fatigue behavior of the aluminum domes under solar radiation.

1. Introduction

According to the advantages of strength-to-weight ratio, lightness, corrosion resistance and ease of production, aluminum members are being used increasingly in structural applications, especially in space structures. The first important aluminum dome, called "Dome of Discovery" was built in UK in 1951 for the Festival of Britain as shown in Fig. 1 [1]. It was the largest in the World at that time, with a diameter of 100 m and a total weight of 24 kg/m^2. The largest in the World, with a diameter of 144 m, have been erected in the ENEL plant of Torrevaldaliga Nord, Civitavecchia, Italy as shown in Fig. 2 [1]. Up until now, there are more than 6000 spatial structures using aluminum alloy material as main structural member.

Because of the Young's modulus of aluminum is roughly one-third of steel that may cause aluminum member to fail by buckling easily, many studies have been carried out to investigate the mechanical behavior of beam-columns members under axial compression and bending [2–10]. However, the expansion coefficient of aluminum is roughly two times of steel that cause aluminum alloy sensitive to the temperature change [11], especially for the non-uniform temperature change under solar radiation [12–14]. There are few investigations referred to the thermal behavior, and the designer is confused during thermal analysis process of aluminum alloy space structures.

Considering the solar radiation, the solar radiation absorption coefficient, the temperature distribution and thermal response of aluminum alloy space structures were systematically analyzed in this paper through theoretical and experimental data.

2. Mensuration of the solar radiation absorption coefficient of the aluminum alloy plate

2.1. Mensuration method

The aluminum alloy plate is a non-transparent material, and radiation is only absorption and reflection when a ray irradiate on the aluminum alloy plate. Therefore, for the aluminum alloy plate, the sum of solar radiation absorption coefficient and solar reflection coefficient is equal to 1. Based on the above analysis, the solar radiation absorption coefficient of aluminum alloy plate can be determined by the following equation:

$$\alpha_S = 1-\rho_s \quad (1a)$$

$$\rho_S = \frac{\sum_1^n \rho_{\lambda i} E_S(\lambda_i)\Delta\lambda_i}{\sum_1^n E_S(\lambda_i)\Delta\lambda_i} \quad (1b)$$

where α_S is the solar radiation absorption coefficient, ρ_S is the solar radiation reflection coefficient, $\rho_{\lambda i}$ is the optical spectrum reflectance

* Corresponding author.
E-mail addresses: hbliu@tju.edu.cn (H. Liu), qhhan@tju.edu.cn (Q. Han).

http://dx.doi.org/10.1016/j.tws.2014.07.007
0263-8231/

for the wavelength with value of λ_i, $E_S(\lambda_i)$ is the spectral intensity of solar radiation when wavelength is equal to λ_i, $\Delta\lambda_i$ is the wavelength interval $\Delta\lambda_i = (\lambda_{i+1} - \lambda_{i-1})/2$, n is the number of measuring point among wavelength range 200–2600 nm.

In this paper, the $\rho_{\lambda i}$ was measured by spectrophotometer. The $E_S(\lambda_i)$ was obtained from Standard ASTMg173-03(2012) as shown in Fig. 3. Fig. 2 shows that the solar radiation at the surface are mainly concentrated from wavelength 280 nm to 2500 nm, and little solar radiation exists in the wavelength 2500–4000 nm and 0–2800 nm. Therefore, the $\rho_{\lambda i}$ was measured by spectrophotometer for wavelength 250–2500 nm.

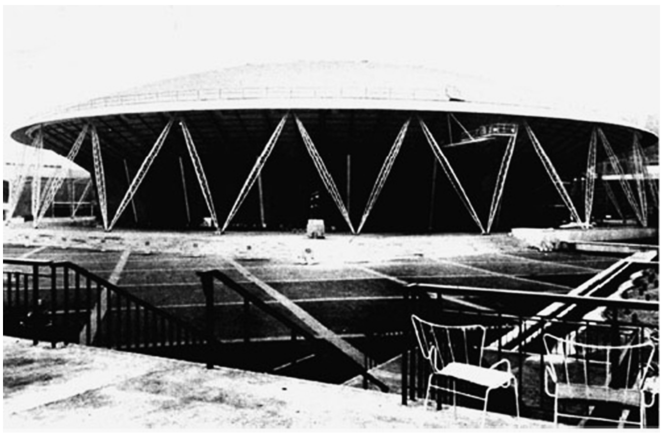

Fig. 1. Dome of Discovery.

Fig. 2. ENEL plant of Torrevaldaliga Nord.

In order to analyze the effect of the thickness of aluminum alloy plate on the solar radiation absorption coefficient, three group specimens were designed with different thicknesses as listed in Table 1.

2.2. Results analysis

The results are listed in Table 1 and the following conclusions were obtained:

(1) the thickness of aluminum alloy plate has effect on the solar radiation absorption coefficient, but the effect will decrease with the increase of thickness and
(2) the solar radiation absorption of aluminum with thickness of 1 mm, 1.5 mm and 2 mm were 0.39, 0.43 and 0.45, respectively.

3. Mensuration of the temperature of the aluminum alloy plate under solar radiation

3.1. Mensuration method

In order to provide insights into the temperature distribution of aluminum under solar radiation and provide data to verify future numerical analysis results, a rectangular aluminum alloy plate with dimension $-1000 \times 500 \times 10$ and three rectangular aluminum alloy plate with dimension as listed in Table 1 were measured to obtain its temperature distribution under solar radiation as shown in Fig. 2. In this test, contact temperature measuring instrument was used to obtain the temperature value of each measured point.

In order to avoid the effect of ground reflection radiation, the specimens were glued to the top surface of a cystosepiment box, and the thermocouple wire was passed through top surface and was out at the side surface as shown in Fig. 4.

Table 1
The specimen size and results.

	Length and width (mm)	Thickness (mm)	Absorption coefficient
Group A	50×30	1	0.39
Group B	50×30	1.5	0.43
Group C	50×30	2	0.45

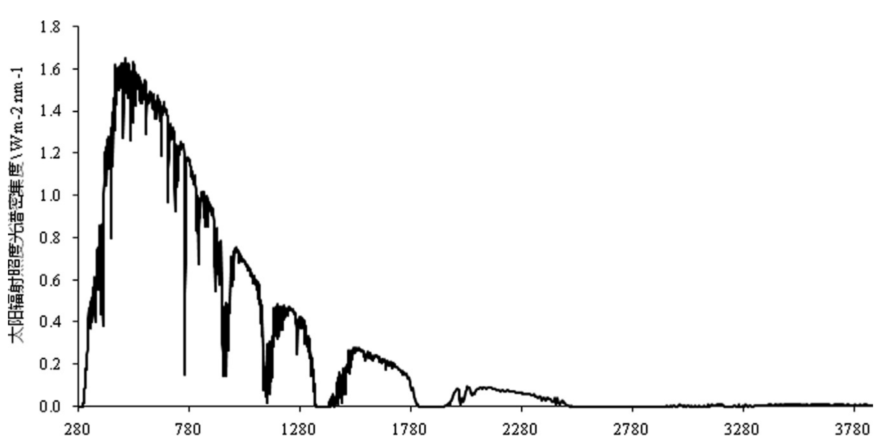

Fig. 3. Spectral irradiances of global solar radiation.