Research on Measurement Technology of Coefficient of Thermal Expansion of Honeycomb Structure

Xiaojun Tang [1, a], Lixia Liu [1, b], Guobao Dai [1, c], Zijie Sun [1, d], Yaodong Yang [1, e] and Ao Li [2, f]

[1]Beijing Spacecraft, China Academy of Space Technology, Beijing 100094, China

[2]North China Institute of Aerospace Engineering, Langfang 065000, China

[a] xiaojuntang87@sina.com, [b] Liu-LX2020@castbsc.cn, [c] guobaodaishuoyan@126.com,

[d] sunzj@castbsc.cn, [e] yaodongyang99@163.com, [f] ipf1284895850@163.com

Abstract. Honeycomb structure is widely used as the main sandwich layer of load-bearing structure in aviation, aerospace and other fields because of its light weight and high strength. Under some service conditions, the deformation of the honeycomb structure affected by high and low temperature will affect the overall mechanical performance of the structure. Therefore, accurate evaluation of the thermal expansion performance of the honeycomb structure becomes the key to structural design. However, the existing measurement methods of thermal expansion coefficient mainly have problems such as the hollow structure cannot be effectively contacted, the area of the grid optical target is limited and difficult to detect. In view of the above conditions, in this paper, a method for measuring the thermal expansion coefficient of honeycomb structure is proposed, and the measurement system is built, and the thermal expansion performance of honeycomb structure is effectively obtained by testing the honeycomb structure. At the same time, the measurement accuracy of the system is verified by using standard test pieces. The experimental results show that the method has high measurement accuracy.

Keywords: Honeycomb structure; coefficient of thermal expansion; video extensometer.

1. Introduction

Honeycomb sandwich structure is a kind of two-dimensional periodic structure, which is a commonly used lightweight load-bearing structure in engineering at present. The common geometric topological configurations of honeycomb are mainly triangular, hexagonal or beige grid configurations [1]. Because this type of structure has the characteristics of light weight, high specific strength and specific stiffness, this type of structure is widely used as a sandwich layer as a main load-bearing structure in the fields of aviation, aerospace, shipbuilding, and other fields [2]. Especially in the aerospace field, spacecraft have strict requirements on the quality and strength of the overall structure. Honeycomb core skin structures are widely used in load-bearing structures such as structural plate, support tubes, and mounting brackets. This type of structure is affected by the high and low temperature alternating environment under the rail service condition, and there is thermal deformation between the skin and honeycomb core on the structure surface [3]. When the thermal expansion rate of honeycomb core and skin is significantly different, there is large thermal stress at the joint between the skin and honeycomb core on the structure surface under the temperature changing environment, which is very easy to cause skin wrinkles, cracks, even delamination and other damage, and make the structure performance failure. Therefore, in the development stage, accurately obtaining the thermal expansion performance of honeycomb core is the key to ensure the service stability of spacecraft [4-6].

The honeycomb core structure is mainly hollow grid structure, and the relative uniformity of material distribution is poor, which cannot be evaluated by using the thermal expansion performance of the known materials. At the same time, due to the grid distribution of the honeycomb core structure, its boundary is mostly a single point contact. The traditional thermal expansion measurement system cannot effectively contact the honeycomb structure, and there is a large random error in the measurement. At the same time, the projection of the honeycomb end face of the honeycomb core structure is a grid line, and the optical projection area is limited [7]. The traditional visual measurement method cannot effectively capture the characteristic points of the measurement surface, and cannot effectively obtain its thermal deformation [8]. In this paper, a video extensometer measurement method suitable for measuring the thermal expansion coefficient of honeycomb grid structure is proposed, and a test system is built. The video extensometer is used to track and measure the characteristic targets on the honeycomb core structure, obtain the deformation field information of the honeycomb structure under high and low temperature environment, and effectively evaluate the thermal expansion performance of the honeycomb structure.

2. Test System

In order to realize the precise measurement of honeycomb core deformation under the high and low temperature environment, this paper has carried out the design of the honeycomb core thermal expansion performance measurement system based on the video extensometer measurement technology, which is mainly composed of the high and low temperature test chamber with optical observation window, the video extensometer measurement system, the high stability measurement support and the nitrogen system.

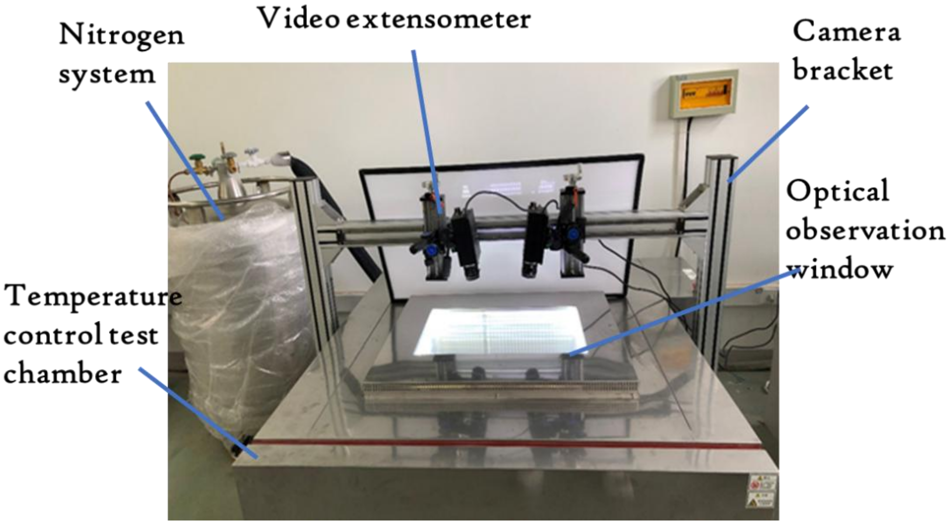

Fig.1 Honeycomb core thermal expansion measurement system

The high and low temperature test chamber is mainly used to load the test piece in the high and low temperature environment. It mainly relies on the internal temperature field of the chamber to achieve quantitative control through the combination of the temperature sensor inside the chamber and the heating and cooling function of the chamber. The cooling of the chamber mainly depends on the low-temperature liquid nitrogen pipeline in the liquid nitrogen system and the low-temperature nitrogen after gasification. The video extensometer measurement system is mainly used to detect the deformation of the honeycomb core structure measured through the optical observation window. Two charge-coupled device cameras (CCD) are installed on the bracket above the observation window as image acquisition devices. The high stability measurement bracket is mainly composed of a low-expansion material bracket and a vibration isolation device. Low-expansion material support is mainly used to reduce the impact of the overflow heat of the high and low temperature test chamber on the stability of the measuring camera, and the vibration isolation devices are mainly used to isolate the vibration and noise impact of the system on the measurement device.

3. Test Verification

In order to verify the feasibility of the measuring system, the thermal expansion performance of honeycomb core structure is tested by using the measuring system. The sample with processed characteristic target is placed in the temperature control box, and is heated from room temperature (30 ℃) to 130 ℃ at intervals of 20 ℃, and the thermal deformation of the sample is recorded by video extensometer.

As shown in Fig.2, in order to solve the problem that the grid structure has enough measurement target area, 8 low-expansion optical identification points (i.e. A1~A8) are respectively set on the sample along the edge of the sample using high-temperature resistant epoxy resin adhesive, and the test sampling lines along the L and W directions of the sample are respectively set, so as to obtain the thermal expansion deformation of the sample in the in-plane direction. The corresponding relationship between optical identification point and test sampling line is:

L direction: sampling line L1 (A1-A3), L2 (A2-A4);

W direction: sampling line W1 (A5-A7), W2 (A6-A8);

The above sampling settings can effectively measure the in-plane thermal deformation (L direction and W direction) of honeycomb core test pieces at the same time, and ensure that there is always ≥ 1 group of valid test results in each direction of the sample during the test. At the same time, in order to verify the measuring accuracy of the measuring system, during the test, a standard aluminum test piece with known thermal expansion coefficient is synchronously placed in the effective measuring area of the video extensometer, and a group of test sampling lines (C1) are also set on the standard test piece using the optical identification point of low expansion rate, as shown in Fig.3.

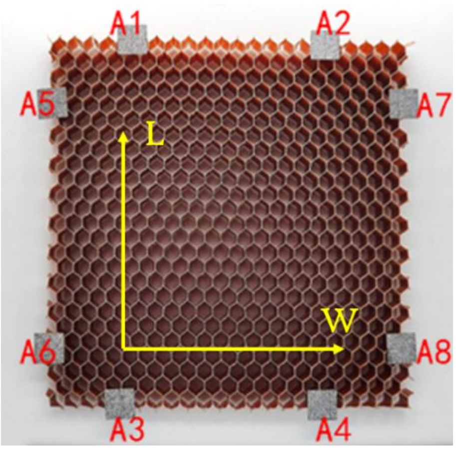

Fig.2 Test sample display and sampling point distribution

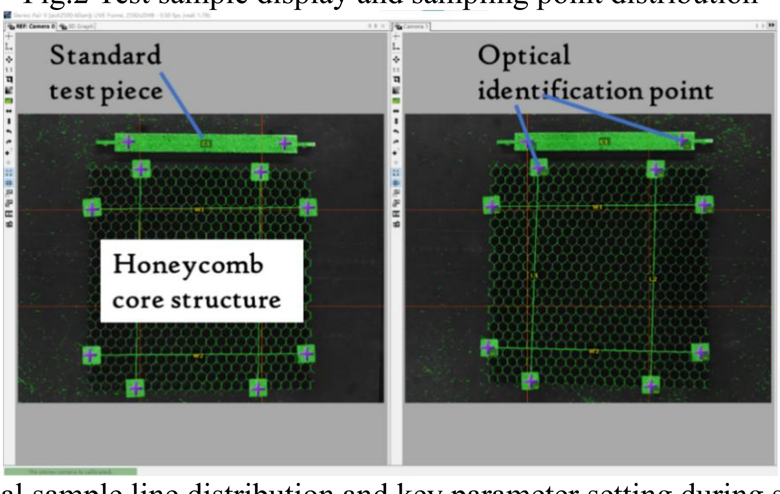

Fig.3 Actual sample line distribution and key parameter setting during sample test

In the process of experimental measurement, the sampling frequency of the camera is set to 1/2 Hz, that is, the thermal strain of the test piece is recorded in real time by shooting multiple digital images at 2.0 s intervals. Considering the hysteresis of the thermal deformation of the test piece and ensuring that the temperature distribution of the whole sample is uniform, an interval of more than 45.0 min is set between each temperature section in this experiment, and the deformation measurement is carried out in the whole process. At the same time, take at least 100 groups of measured data as the effective data at this temperature, and homogenize the data to reduce the impact of external environmental factors and equipment deformation factors on the results.

4. Test Results and Analysis

4.1 Thermal Expansion Test Results of Honeycomb Core Structure

During the experiment, two sets of test sampling lines are set up in the L direction and W direction respectively for the sample, namely, L1, L2, W1 and W2. The thermal strain produced by the test sample line with the temperature change is shown in Fig.4, where the thermal expansion trend of the tested piece in the L direction and the thermal shrinkage trend in the W direction.

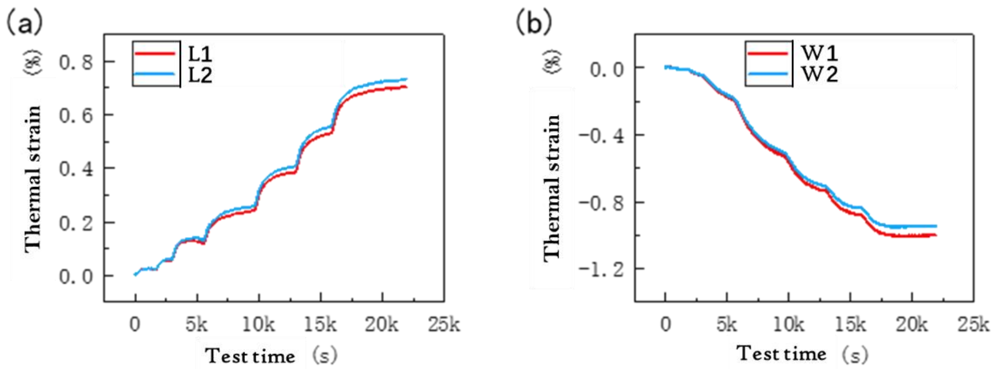

Fig.4 The thermal strain of the sample (a) along the L direction and (b) along the W direction along each test sample line as a result of temperature change

At the same time, in order to further quantify the thermal expansion performance of the test piece, from the test data of each sampling line, five groups of valid data within each temperature range are selected for average processing as the thermal deformation test data of the sample at five different temperatures of the sampling line, and the thermal deformation test data of the sample at different temperatures are fitted with a linear curve. The time sampling interval of test data at each temperature is: 1400 s - 1600 s (30 ℃, 200 s, 100 groups of data), 5400 s - 5600 s (50 ℃, 200 s, 100 groups of data), 9400 s - 9600 s (70 ℃, 200 s, 100 groups of data), 12800 s - 13000 s (90 ℃, 200 s, 100 groups of data), 15600 s - 15800 s (110 ℃, 200 s, 100 groups of data) and 21000 s - 22000 s (130 ℃, 1000 s, 500 groups of data), The sampling data in each temperature range shall not be less than 100 groups. Fig.5 shows the average thermal strain data in each temperature range.

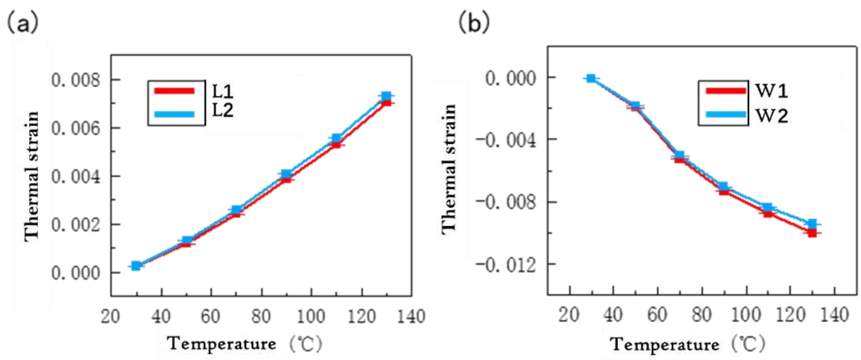

Fig.5 Average thermal strain of sample (a) along L direction and (b) along W direction at different temperatures

According to the definition of thermal expansion coefficient, that is, the thermal expansion coefficient is equal to the thermal strain under unit temperature change, so the slope of each linear fitting curve is the equivalent thermal expansion coefficient measured by the corresponding sampling line. According to the fitting calculation of the thermal expansion coefficient corresponding to the temperature of each curve in Fig.5, the final test results of the equivalent thermal expansion coefficient of the sample along the L and W directions are 69.09×10^{-6} /℃ and -96.31×10^{-6} /℃. Moreover, the thermal expansion performance of the sample along the W direction shows a significant decrease with the increase of temperature. In the range of 30 ℃ - 130 ℃, the equivalent thermal expansion coefficient of the sample along the W direction ranges from -160.75×10^{-6}/℃ gradually reduces to -53.89×10^{-6} /℃.

4.2 Thermal Expansion Test Results of Standard Test Pieces

During the experiment, the thermal strain of the test sample line (C1) set on the standard aluminum test piece is measured synchronously, and the processing method is the same as that of the honeycomb core test piece. The continuous thermal strain collection is carried out. Fig.6 shows the thermal strain generated by the test sample point with the change of temperature.

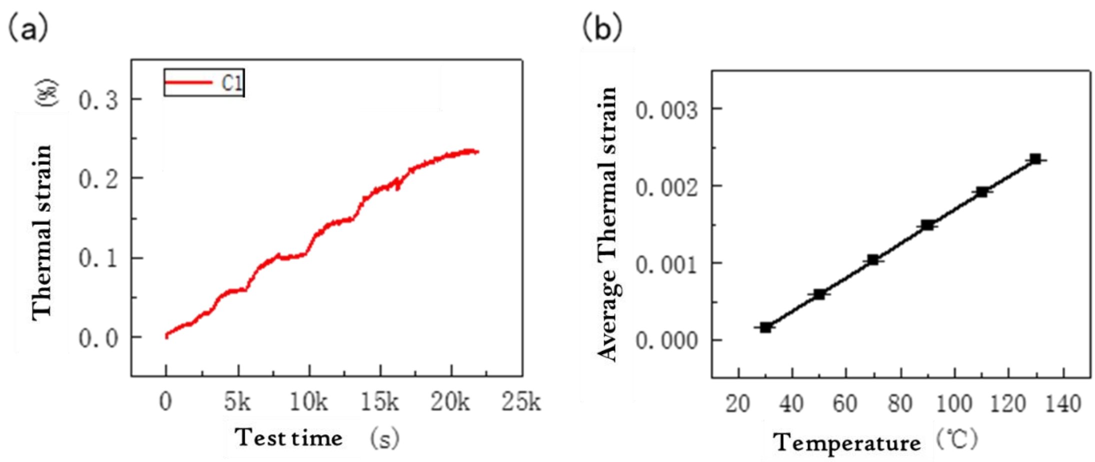

Fig.6 (a) Test the thermal strain of standard parts; (b) Mean value of thermal strain of standard parts in each temperature range

Consistent with the processing method of honeycomb core measurement data, the measurement results in each temperature range are processed by mean value, and the thermal deformation test data of the sample at different temperatures are fitted by a linear curve to obtain the thermal expansion coefficient of the standard test piece. As shown in Fig.10 (b), the test results of the equivalent thermal expansion coefficient measured at each temperature section of the standard test piece are 21.7×10^{-6} /℃, 21.9×10^{-6} /℃, 22.6×10^{-6} /℃, 21.8×10^{-6}/℃ and 21.1×10^{-6} /℃. The average thermal expansion result of the standard test piece is 21.80×10^{-6}/℃ (i.e. 21.80 ppm/℃). In contrast, the average thermal expansion coefficient of aluminum standard test piece in the range of 30 ℃- 130 ℃ measured by a special thermal expansion instrument (DIL) is 21.675×10^{-6}/℃, so the measurement accuracy of thermal expansion coefficient of the test system is 0.2×10^{-6} /℃.

5. Conclusion

In this paper, a video extensometer measurement method suitable for the measurement of thermal expansion coefficient of honeycomb grid structure is proposed, which effectively solves the problem of difficult identification of optical characteristic targets with limited measurement area of honeycomb core grid structure. It has the advantages of simple operation, multi-dimensional synchronous measurement, high accuracy, non-contact, and so on. The measurement system was built using this measurement method, and the thermal expansion coefficient of honeycomb core grid structure was measured. The thermal expansion coefficient in two directions in the honeycomb core structure plane was effectively obtained, and the law of thermal expansion in one direction and thermal shrinkage in one direction of the honeycomb core was found. At the same time, the accuracy of the measurement system was measured using the standard test piece with known thermal expansion coefficient, and the measurement results showed that the measurement accuracy of the system was better than $0.2 \times 10^{-6}/℃$, which can more accurately evaluate the coefficient of thermal expansion of honeycomb core and other grid hollow structures. This measurement method can also be applied to the thermal deformation measurement of other anisotropic and non-uniform structural parts, providing a new measurement idea for the in-plane multi-dimensional thermal expansion coefficient measurement of complex test pieces.

Acknowledgments

This work was sponsored by Beijing Nova Program (No.2022095).

References

[1] Yoshihiko Arao, Jun Koyanagi, Hiroyuki Kawada. Analysis of Thermal Deformation on a Honeycomb Sandwich CFRP Mirror[J]. Mechanics of Advanced Materials & Structures,2010,17(5).

[2] Li Dong, Yin Jianhua, Dong Liang. Strong re-entrant cellular structures with negative Poisson's ratio[J]. Journal of Materials Science,2018,53(5).

[3] ZHENG Fa-Song, DING Ying-Chun. The Approach of Compensation of Air Refractive Index in Thermal Expansion Coefficients Measurement Based on Laser Feedback Interferometry[J]. Chinese Physics Letters,2015, 32(7).

[4] HE Yanlin, ZHU Lianqing, SUN Guangkai, et al. Design, Measurement and shape reconstruction of soft surgical actuator based on fiber Bragg gratings[J]. Applied Sciences, 2018, 8(10):1773.

[5] SONG Shuang, LI Zheng, YU Haoyong, et al. Electromagnetic positioning for tip tracking and shape sensing of flexible robots[J]. IEEE Sensors Journal, 2015, 15(8):4565-4575.

[6] Tochukwu George, Vikram S. Deshpande, Keith Sharp, et al. Hybrid core carbon fiber composite sandwich panels: Fabrication and mechanical response[J].Composite structures, 2014,108 (2).

[7] R. Velmurugan, M. Buragohain. Study of filament wound grid-stiffened composite cylindrical structures[J]. Composite structures, 2011, 93 (2).

[8] Shan-shan Shi, Zhi Sun, Xiao-zhi Hu. Carbon-fiber and aluminum-honeycomb sandwich composites with and without Kevlar-fiber interfacial toughening[J]. Composites Part A:Applied Science & Manufacturing, 2014, 67(A).