proceedings

Proceeding

Fibers Do the Twist Can Have an Adjustable Thermal Expansion†

DongHua Yue[1*], LiMing Wei[1]

[1] Institute of Systems Engineering, China Academy of Engineering Physics, Mianyang 621999, P. R. China

* Correspondence: lxyuedh@caep.cn; Tel.: +86-816-2494848

† Presented at 18th International Conference on Experimental Mechanics (ICEM18), Brussels 1-5 July 2018.

Published: date (leave it empty)

Abstract: In this paper, a device with high accuracy capacitive sensor (with the error of 0.1 micrometer) is constructed to measure the axial thermal expansion coefficent of the twisted carbon fibers and yarns of Kevlar. A theoretical model based on the thermal elasticity and the geometrical features of the twisted structure is also presented to predict the axial expansion coefficient. It is found that the twist angle, diameter, and pitch has remarkable influences on the axial thermal expansion coefficients of the twisted carbon fibers and Kevlar strands, and the calculated results take good agreements with the experimental data. We can found that, with the increase of the twist angle, the absolute value of the axial thermal expansion coefficient increases. For the Kevlar samples, the expansion coefficient will grow by about 46% when the twist angle increases from 0 to 25 degrees, while for the carbon fiber samples, which will grow by about 72% when the twist angle increases from 0 to 35 degrees. The experimental measurements and the model calculations reveal important properties of the thermal expansion in the twisted structures. Most notably, the expansion of the strand during heating or cooling can be zero when the twist angle is around β=arcsin(αL/αT)^1/2. Where β denotes twist angle of the strand, αL, αT is the longitute and the transverse thermal expansion coefficient of the strand, respectively. According to the present experiments and analyses, a method to control the axial thermal expansion coefficient of this new kind of twisted structure is proposed. Moreover, the mechanism of this tunable thermal expansion is discussed. Based on the model, a method which can be used to rectify the thermal expansion properties of the twist structures is established. This may be a new way of fabricating zero expansion composite materials in the future.

Keywords: twisted structure; carbon fibre; tunable thermal expansion coefficient

1. Introduction

The coefficient of thermal expansion (CTE) is one of the most important parameter of thermal physical properties. Materials and structures with adjustable thermal expansion are urgently needed in engineering applications, especially in precision instruments, aerospace, and civil engineering, where the control of thermal expansion and stress due to a wide range of temperature is very important[1]. Therefore, the development of materials or structures with tunable thermal expansion has important scientific significance and engineering application. At present, the new concept of zero thermal expansion rope twisted by polymers and carbon fibers has been investigated herein according to its distinguishing advantages e.g. high energy density, large-stroke, non-hysteresis, and inexpansive[2, 3].The structure of twisted-wire are widely used in engineers, electric cable, bridge, drilling platform and else. That's because their ability to resist axial load and flexible in bending[4]. It's important to test and calculate the thermal expansion exactly. There are several key factors have a strong impact on the thermal expansion of twisted wire. The pitch of the strand and contact force even the friction can change the thermal expansion characteristics of the twisted-wire. The fabrication process of this kind of artificial muscle is very simple and convenient, and the deformation principle of which is in response to the thermal expansion.

2. Experiment

In this paper, a device with high accuracy capacitive sensor (with the error of 0.1 micrometer) is constructed to measure the axial thermal expansion coefficent of the twisted carbon fibers and yarns of Kevlar. The twisted-pair strand was formed by two bundles of fibers, with the angle of $\alpha = 12^{\circ}/13^{\circ}/17^{\circ}/25^{\circ}$ for Kevlar strand and $\alpha = 10^{\circ}/18^{\circ}/31^{\circ}/35^{\circ}$ for the carbon strand. The twisted angle of the strand was obtained by equation (1):

$$\alpha = \arctan(\frac{\pi D}{h}) \tag{1}$$

Where α denotes twist angle of the strand, h is the pitch of the strand, D is the Diameter of the bundles. The diameter of the carbon fiber bundles and strands are 1mm and 2mm respectively. The diameter of the Kevlar fiber bundles and strands are 0.45mm and 0.9mm, and the length of the samples were about 250mm. The experiments were performed at room temperature 20℃. 25% of the elastic limit was chosen as the preload. The slope of the displacement and temperature curve was used to calculate the thermal expansion coefficient. A self-made device for measureing the axial thermal expansion coefficient of parallel fiber and two-ply strand was constructed by using the capacitive displacement sensor inside a quartz tube which was wrapped in heating wire, as shown in Figure.1.

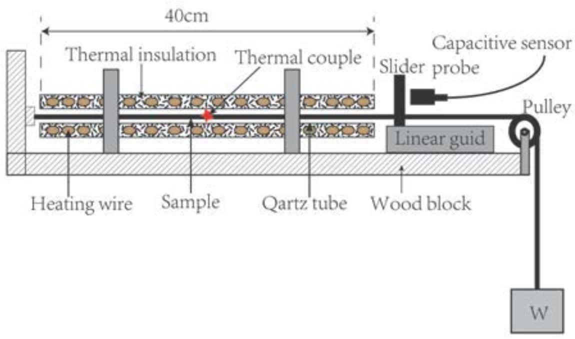


Figure 1. Schematic of the apparatus used to measure the axial thermal expansion coefficient.

The test system was fixed on the damping platform. The effect of the friction in the guide rail and the pulley can be neglect as the force is so small compared with the hanging weight. Thermometer has been slipped every centimeter to measure the temperature along the tube .The temperature change profile is shown in Figure 2 .

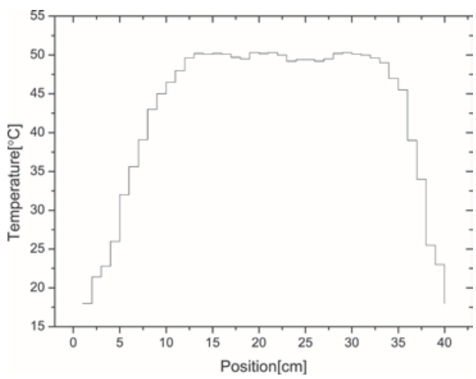


Figure 2. Temperature distribution in the heating tube

Temperature fluctuation in the tube are the main sources of error in the experiment at level of roughly $\pm 0.6°\mathrm{C}$. Temperature change profile was then used to calculate the length of the effective homogeneous area. The effective homogeneous length is 32cm with the equivalent elongation of integral by divided into 1cm sections. The thermal expansion coefficient of sample is defined as

$$\alpha_{eff} = \frac{\Delta L}{L_{eff}\left(T_{High} - T_{Low}\right)} \tag{2}$$

Where ΔL is the contraction of the samples when temperature rises, T_{High} and T_{Low} are the heating temperature and initial Temperature respectively. The effective length of the homogeneous area can be expressed by

$$L_{eff} = \int_0^L \left(T - T_{Low}\right) dL / \left(T_{High} - T_{Low}\right) \tag{3}$$

This assumption will not affect the integrity of the results calculated in this paper. The previous results show that when the thermal expansion of carbon fiber was measured around $25°\mathrm{C}$, the thermal expansion is -1.17×10-6 K^{-1}. The calculated thermal expansion is -1.2×10-6 K^{-1} with the effective length with ours test results.

3. Results and disscussion

The results of carbon sample are shown in Figure. 3a and Figure.3b, where the twisted angle is $\alpha = 31^{\circ}$. The contractions of the Kevlar parallel fibers and strand with the twist angle $\alpha = 25^{\circ}$ are shown in Figure.4a and Figure.4b.

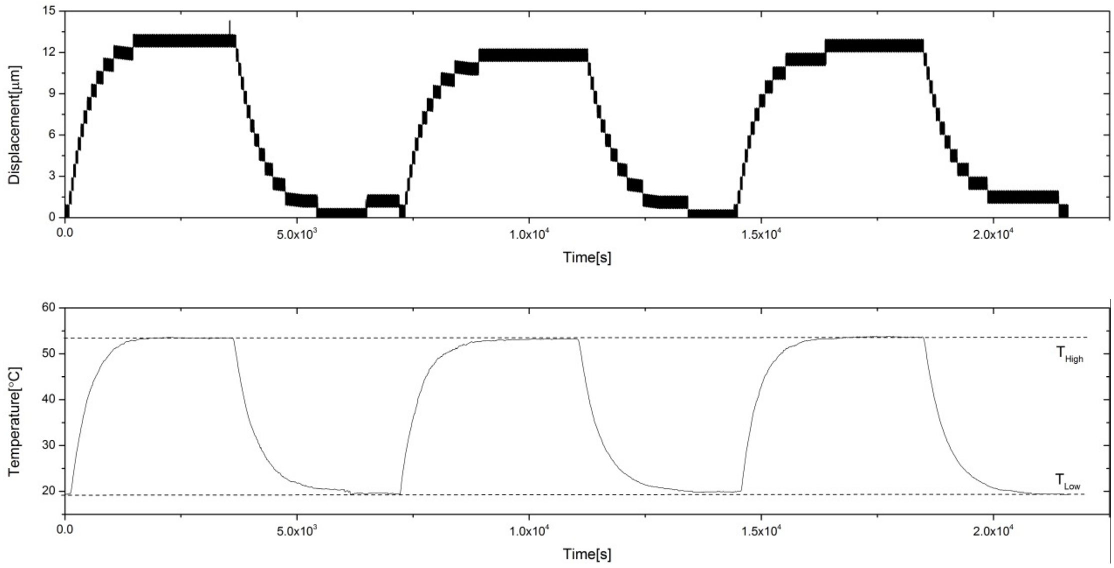
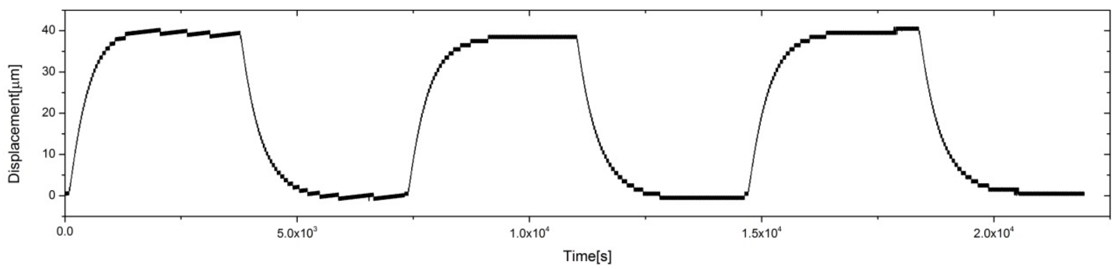


Figure 3a. Contraction of the carbon fiber bundle with the twist angle $\alpha = 0$



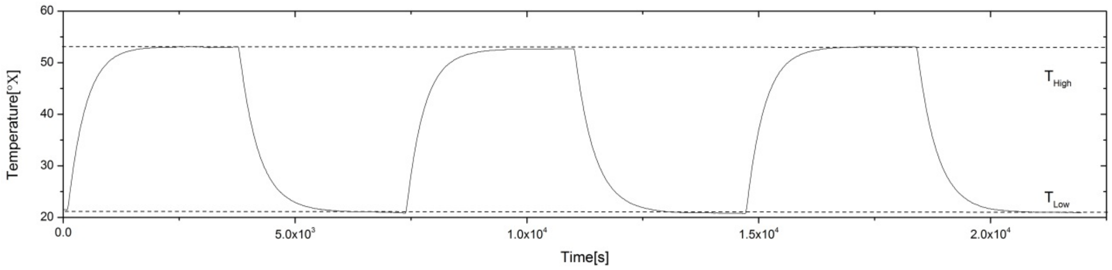


Figure 3b. Contraction of the carbon fiber strand with the twist angle $\alpha = 31^{\circ}$

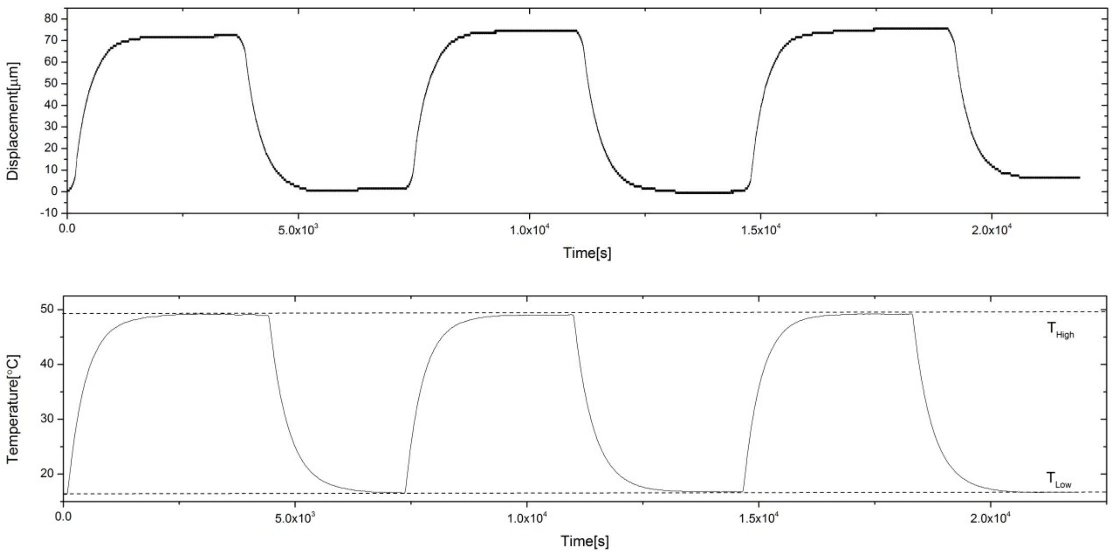


Figure 4a. Contraction of the Kevlar-29 fiber bundle with the twist angle $\alpha = 0^{\circ}$

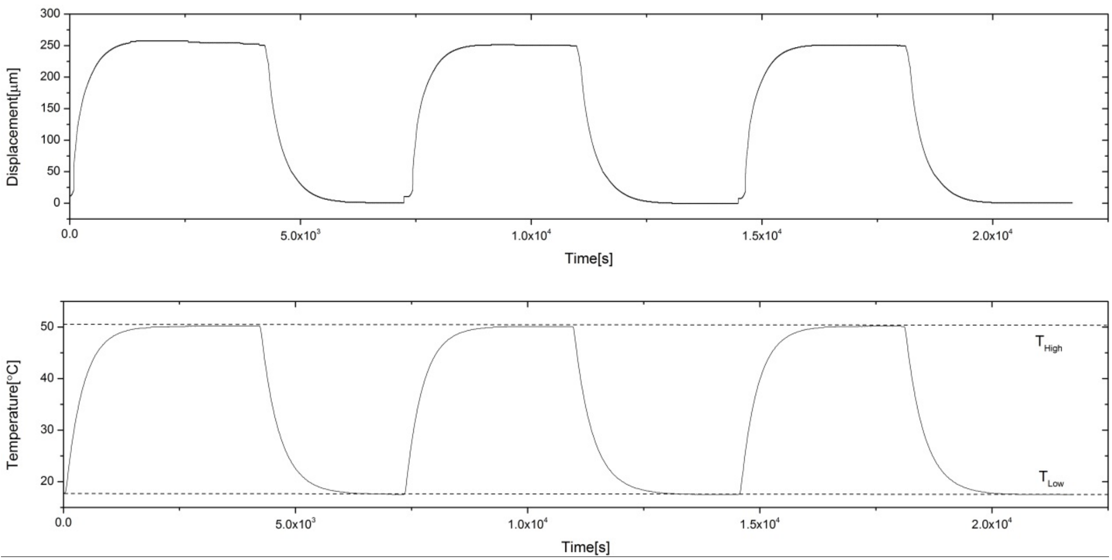


Figure 4b. Contraction of the carbon fiber strand with the twist angle $\alpha = 25^{\circ}$

As considered the thermomechanical mechanism and qualified the thermal stress in the strand when being heated. A theoretical model was obtained to quantify the axial expansibility of the strand twisted by anisotropic fibers. The coefficient of thermal expansion of the strand can be defined as

$$\alpha_{eff} = \frac{\alpha_L - \alpha_T \sin^2 \alpha}{\cos^2 \alpha} \tag{4}$$

Comparison of theoretical and experimental effective thermal expansion coefficient against the twist angle is shown in figure 5.The dot symbols denote the thermal expansion coefficients of tested results. The dot-lines are on behalf of the calculating results according to the above module. From this equation we can predict the giant contraction in strand resulting from the anisotropic of thermal expansion coefficients. One can see that the theoretical results are in good agreement with the experimental results.

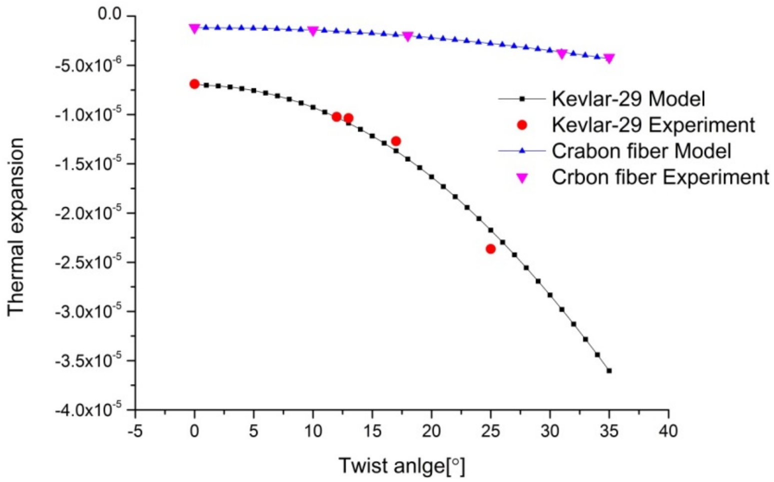


Figure 5. The adjustable axial thermal expansion coefficient of the strand varies with the twist angle.

4. Conclusion

In summary, the axial thermal expansion coefficient of the twisted-pair strand during heating and cooling were measured. It was found that the coefficient of the amplification due to twisted associated with two factors: the degree of twisting and the degree of anisotropy of the thermal expansion coefficient. The relationships between degree of twisting and axial thermal expansion coefficient has been obtained, and verified by experiment with Kevlar and carbon fibers strand. According to the theoretical analysis we can get more contractive rope by twist the strands together. Therefore, the expansion of the strand during heating or cooling can be zero when the twist angle around $\beta = \arcsin\sqrt{\alpha_L / \alpha_T}$. This is a new way of fabricating zero expansion composite materials in the future.

Acknowledgement

This work is supported by the Innovation and Development Fund of institute of systems engineering (No.2017 cxj10).

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