

# FBGS 在纺织复合材料中检测的可行性及有效性

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摘要: 分析了纤维布拉格光栅传感器(FBGS)埋入纺织复合材料中的可行性及有效性, 结果表明 FBGS 埋入复合材料中不影响所测物体的应变场, 在一定条件下, FBGS 所测得的应变和温度能代表所测物体的应变和温度。

关键词: 纤维布拉格光栅传感器(FBGS) 测量 可行性 有效性

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随着技术和经济的发展, 要求有更多质地轻、强度高、韧性和柔性好的材料, 纺织结构作为增强件的复合材料较好地满足了这些要求, 因而在近几十年受到广泛重视。为了发展具有坚实基础的结构复合材料工业, 充分发挥纺织结构复合材料的优越性, 需要以先进测试方法来表征各类纺织复合材料的特性。智能纺织结构复合材料是利用埋入材料中的传感元件来感受各种信息, 经过处理分析, 然后指示或控制驱动件工作。其中光导纤维具有感测和传输双重功能, 具有直径小、质量轻、柔韧易弯曲、传输带宽高、抗电磁干扰、便于波分及时分复用等优点。用光纤组成的传感器, 可测量温度、压力、速度、流量、位移、电磁场等<sup>[1~8]</sup>多种物理量并具有极高的灵敏度。在织物结构中植入光纤传感器, 可对纺织复合材料进行质量信息控制, 如: 纺织复合材料加工过程中在线监测复合材料内部应力/应变场的分布; 使用过程中的安全监测和损伤评定; 将控制系统和监测器连成一体, 并对工作环境的变化作出响应。因此光学智能纺织复合材料在各种工程领域将有重大的应用前景。另外作为一种科技含量高、高附加值的产品, 光纤智能纺织复合材料还会给纺织业带来巨大的经济效益。

## 1 FBGS 埋入纺织复合材料中的可行性

若光纤布拉格光栅(FBG)栅距为  $\Lambda$ ,  $n_{\text{eff}}$  为光纤纤芯的有效折射率, 则注入光波  $\lambda$  满足布拉格衍射条件  $\lambda_B = 2n_{\text{eff}} \Lambda$  时, 该波长的光波将被反射回, 被反射回的光波就是布拉格反射光。光栅周期或折射率变化将引起反射光波长的变化。应变引起的膨胀和收缩使光栅周期发生变化且产生应变-光效应, 从而影响布拉格响应。温度引起的膨胀和收缩使光栅周期发生变化且产生热-光效应, 也影响布拉格响应。光纤光栅的布拉格波长变化  $\Delta\lambda$ , 取决于承受的应变  $\epsilon$  和温度变化  $\Delta T$ 。

$$\frac{\Delta\lambda}{\lambda} = \epsilon_1 \left\{ 1 - \frac{n^2}{2} \left[ P_{12} + \frac{\epsilon_2}{\epsilon_1} (P_{11} + P_{12}) \right] \right\} + \alpha \frac{n^2}{2} (P_{11} + 2P_{12}) \Delta T + \xi \Delta T = f\epsilon_1 + \xi^* \Delta T$$

$$f = 1 - \frac{n^2}{2} \left[ P_{12} + \frac{\epsilon_2}{\epsilon_1} (P_{11} + P_{12}) \right]$$

$$\xi^* = \xi + \alpha \frac{n^2}{2} (P_{11} + 2P_{12})$$

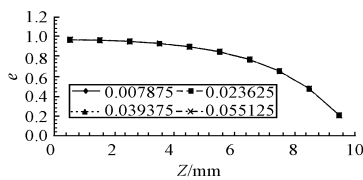
式中,  $f$  为传感器的灵敏度系数;  $\xi^*$  为修正的热光系数;  $P_{ij}$  为基体的光应变系数;  $\alpha$  为热膨胀系数,  $\epsilon_2/\epsilon_1$  为有效泊松系数。

灵敏度系数随着有效泊松系数的增加而增加, 当用 FBGS 作为包埋传感器时, 必须就横向应变作一灵敏度系数校正, 否则只有当光纤的横向应变对基体应变场不敏感时, 灵敏度系数才可作为一常数。

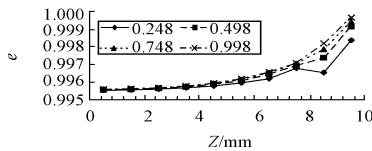
## 2 FBGS 埋入纺织复合材料中的有效性

布拉格光栅传感器(FBGS)作为一种理想的应力/应变传感器, 其有效性是人们所最为关心的, 特别是关于光纤的应变能否影响物体原有的应变场; 另一方面, 光纤的应变是否等于物体所测处周围的应变。为此文献[9]设计了一种特殊情况: 作用热载荷于埋有光纤的物体, 然后求解光纤与物体的应变场。如两者应变场一致, 结果理想; 如不一致, 研究出影响因素。光纤一般由高分子涂层保护, 因此是求解在恒定热载荷作用下由 3 种物质组成的复合体的应变场得到的结果。设计成 3 层复合圆柱体模型, 见图 1, 复合材料由内到外 3 层依次是圆柱体光纤、圆筒体的光纤涂层和物体。这里假设光纤、光纤涂层和物体是线弹性体, 热膨胀系数是常数, 界面是整数; 热载荷均匀作用在复合体上, 所以其是个轴对称体, 可用对称工具 ABAQUS, 以轴对称双线性四结点单元(CAX4)分析半圆柱体。设没有埋光纤时物体应变为  $\epsilon_0$ , 以  $\epsilon_0$  来归一化所有计算出的应变值,

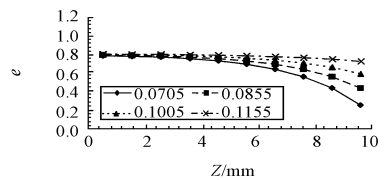
轴向应变  $\epsilon_z$ , 则归一化轴向应变  $e = \epsilon_z / \epsilon_0$ 。由图 2 (a), (b), (c), 得到以半径  $r$  为参数的光纤、物体和光纤涂层应变沿  $Z$  轴的空间分布。在光纤内部的几条曲线基本重合, 说明  $r$  的影响小, 也就是光纤测的应变场沿径向是均匀的, 应变是  $Z$  的函数。因为光纤的热膨胀系数比物体小 1 个多数量级, 因此光纤的应变很大程度上受到物体的限制。由于光纤中间部分受到限制比两端多, 因此光纤中间部分的应变更接近于未埋光纤传感器物体的应变 ( $e=1$ )。物体应变随  $Z$  的变化与光纤的相反, 因物体中间的应变受光纤的约束较大而应变小, 而靠边界因约束小而膨胀充分, 总的来讲物体的应变变化很小, 而物体的所有应变均大于 0.995, 很接近无光纤时物体的应变。这说明包埋与不包埋光纤传感器物体的应变非常接近, 传感器所测应变代表了所测处的物体的应变。光纤涂层的弹性模量很小, 它的应变受光纤和物体的影响很大, 其



(a) 光纤



(b) 物体



(c) 光纤涂层

图 2 光纤、物体、光纤涂层应变场的分布

### 3 结 论

1. 通过 FBGS 埋入复合材料中的可行性分析, 认为 FBGS 埋入复合材料中是可行的, FBGS 能对物体的应变及温度进行测量。

2. FBGS 埋入复合材料中是行之有效的, 包埋与不包埋光纤传感器物体的应变非常接近, 传感器所测应变代表了所测处的物体的应变。

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应变沿  $Z$  的分布是: 当涂层半径接近光纤半径时, 与光纤的应变分布曲线接近, 而当涂层半径接近物体半径(即外层涂层)时变化很小与物体的应变分布曲线接近。随着光纤涂层弹性模量、基体高度、基体与纤维的拉伸刚度比的增加, 光纤测量的有效性也提高。这些参数有一临界值, 超过了临界值, 则有效性提高很小。同时随着光纤涂层泊松系数的增加, 光纤测量的有效性减小, 为确保测量效果, 必须选择合适的涂层, 最有效的方法是适当提高涂层弹性模量, 而且这有助于测量灵敏度系数的稳定。

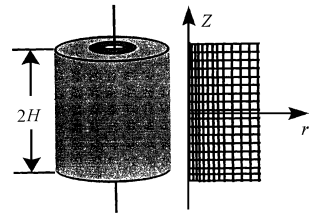


图 1 三层复合圆柱体模型

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parameters, analyze and discuss the dynamic curve and parameters of the motion of rising frame and lifting knife and head. .... Zheng Zhiyu(40)

### **Measure and Research on Braided Angle of Composites Preform**

An algorithm of three-dimensional braided composite material preform image processing based on mathematics morphology is presented. This image of edge is fit to the parameter testing of three-dimensional braided composite material preform. The research is vital important to analyze mechanical property of three-dimensional braided composite material. .... Wan Zhenkai et al(42)

### **Limit Method Analyze the Textile Structural Composites Elastic Modulus**

Analyze the elastic constants of textile structural composites by mosaic model and undulation model of woven fabric composites. The limit of stiffness constants and compliance constants of plain weave are obtained. .... Wang Chunmin(44)

### **The Reliability and Effectiveness of FBGS in Textile Composite**

Concerned with the Feasibility and Effective of Fiber Bragg Grating Sensor (FBGS) embedded in the textile composites. The result indicates that has a little effect on the initial strain field of the host under current investigation, the measurement by FBGS can be regarded as the internal strain and temperature of the host. .... Yang Bin et al(48)

### **The Study of Lamination Technology for Film and Fabric**

The adhesion between film and fabric with different materials and different structure was investigated. The effect of different coating process on adhesion and wettability were introduced. The result showed that the different fabrics possessed difference adhesion and the adhesion increased with the increasing of surface wettability. The moisture permeability and adhesion of complex were affected more by the variety of coating process. .... Luo Xin et al(50)

### **Study the Cellulase Finishing Process for Cotton Fabric by Orthogonal Analyses Method**

Analyze the experimental data by Orthogonal analyses method of factors influence the effect of cotton knitting fabric with biofinishing get a optimized parameters, to optimize the cellulase finishing process and improve the softness, air permeability, hygroscopicity. Better results are obtained for thicker fabrics. .... Huang Chen et al(52)

### **Noise Reduction of Computerized Embroidery Machine Vibration Based on Wavelet**

During computerized embroidery machine tests, wavelet theory is applied and matlab program is made in order to get vibration response of beam without noise and good results are given. .... Zhao Fu et al(55)

### **Research on Relation Between Mechanical Properties of Polyurethane Woven Fabric and Sewing Quality**

Four indexes are introduced to appraise the sewing quality of polyurethane woven fabric. Their relationship between polyurethane woven fabric mechanical properties and sewing quality is studied systematically by means of multivariate statistic analysis, and the major influential factors of sewing quality through polyurethane woven fabric are interpreted. .... Fang Liying et al(57)

### **Study on Digitalization of Chest Silhouette and in Practice**

By carrying on draping the different female body in various relax quantity of body chest. Analyze the regularity of variation in chest silhouette digitalization and groped it for practical application. .... Liu Guanbin(59)

### **Compare the Woman's Pants Pattern between Old Middle-aged and Youth**

Compare the difference in figure, parameter and drawing method of the fitted woman's pants pattern of old middle-aged and youth. Discuss close relationships between bodily form and pants pattern. .... Wu Qiaoying et al(61)

### **The Extend Strategic Model for Fashion Process Location Selection**

Base on the strategic model for fashion process location selection, extend it, at aims of minimize cost and the delivery as well. Fashion companies can use the model flexibly under variety situation and make the practical optimum strategy to fulfill both the punctual delivery and the reasonable cost. .... Hu Jueliang et al(64)

### **Systematic Study on Reducing Reworks in Fashion Manufactory**

Put forward that to reduce reworks is a systems engineering, which need emphasize on strengthen the systems and process, insist on orient to customer, encourage staff participate and teamwork, decisions based on reliable information, improve communication and coordination, demonstrate leadership commitment and make a continuing education plan about quality, etc. .... Yan Yuxiu et al(66)

### **Study on the Color Perception of the Garment**

The principle of the color perception and the methods of color perception measurement are investigated. The visual evoked potentials created by color were obtained. The results show that different colors result in the different level of evoked potentials. Although there are individual differences, the trends of the color evoked potentials are similar. .... Chen Yan et al(68)

## **Technique of Manufacture**

### **The Research on High Speed Spinning Finish Oil TPA-98 for Nylon**

Based on requirements of nylon high-speed spinning process, the spinning finish oil TPA-98 take serial poly-ether have good lubricate and thermal properties as main component and optimized by adjusting its wetting, antistatic and thermal resist properties. It is proved the product have excellent spinnability and higher dyeing uptake. .... Xu Jinyun et al(70)

### **Industrial Test of Graft Flax Fiber (III)**

Ethyl acrylate grafted and co-polymerized flax its physical characteristics gets a great improvement; higher elasticity; better softness. Fabrics have a nice hygroscopicity and wearing characteristics. .... Kang Fusheng et al(72)

### **Primarily Investment into Developing the Palm Leaf Fiber**

The de-gumming method and process of palm leaf and its physical properties are probed. Its chemical composition analyzed. Show that; The palm leaf fiber has good mechanical and physical properties and has a great value for further developing and studying. .... Liu Xiaoxia et al(74)

### **Performance Analysis about Bamboo Pulp Fiber**

The elongation performance and swelling property of bamboo pulp fiber are tested and analyzed. Point out; That the physical properties of bamboo pulp fiber are similar to viscose, high hygroscopicity, weak tensile strength in wet and higher percentage of elongation. Its applications and productions are forecasted. .... Li Ruizhou et al(76)

### **Using the Technique of Picture Treatment to Appraise the Fuzzing Characters of Fabrics of Soybean Protein Fiber**

A method provided by using the technique of picture treatment realized the software programming and image collecting. It is used to appraise the fuzzing characters of fabrics of soybean protein fiber objectively. .... He Jun et al(78)

### **A Trail Discussion on the Characteristic Style of Wool Fabric**

Discuss the contents, the characteristics of style evaluation of wool fabrics and the relative factors they affect the style. .... Wu Qingping et al(80)

### **The Design and Produce of the Loose Weave Double-layer Joining Fancy Suiting**

The analyses and probe of the specific properties, ideas of design, production process and technical requirements of loose weave fancy suiting. .... Zhang Chunfang(82)

### **The Imperfection an Improvement of Knitting Elements Acting on Yarn**

Base on analyze the imperfection of elements acting on yarn, raise two loop formation methods. One is rolling friction between yarns and knitting elements, the other is without slide between yarns and knitting elements. The experiments show the later can also knit in loop form with high strength, high modulus fiber and yarn as well as large loop stitches. .... Zhou Luoqing(84)

### **Study the Antistatic Property of Antistatic Knitted Fabric**

Study the interval between conductive fiber to fiber and contents of conductive fiber in the antistatic knitted fabric in relations with the antistatic property of