Thermal Curing Process Monitoring of the Composite Material Using the FBG sensor

To cite this article: Youhong Zhang et al 2018 IOP Conf. Ser.: Mater. Sci. Eng. 322 022062

View the article online for updates and enhancements.

Related content

- The Packaging Technology Study on Smart Composite Structure Based on The Embedded FBG Sensor
  Youhong Zhang, Xinlong Chang, Xiaojun Zhang et al.

- Composite Shell Strain Detection for SRM Based on Optical Fiber Sensors
  Lei Zhang, Xin-Long Chang, You-hong Zhang et al.

- Numerical and experimental investigation of FBG strain response at cryogenic temperatures
  V. N. Venkatesan and R. Ramalingam
Thermal Curing Process Monitoring of the Composite Material Using the FBG sensor

Youhong Zhang¹,*, Xinlong Chang¹, Xiaojun Zhang² and Xiangyong He¹

¹Xi’an Research Institute of Hi-tech, Xi’an, China
²Xi’an Modern Chemistry Research Institute, Xi’an, China

*Corresponding author e-mail: zyhnpu@163.com

Abstract. The raw composite material will suffer complex chemical and morphological changes during the thermal curing process, and it is difficult to monitor the curing process and curing effect. In this paper, the FBG sensor was embedded in the raw composite material to monitor the whole curing process. The experiment results showed that the FBG sensor can monitor the resin transformation and residual deformation of the composite material, and the FBG sensor can be applied to monitor the thermal curing process of the composite structure.

1. Introduction
Thermal curing process is one of the important steps of the composite material manufacturing course, and in the curing process, the raw material will suffer complex chemical and morphological changes. Therefore, the curing process is very complex and it is difficult to monitor the curing process and curing effect. In the initial thermal curing process, the resin turn into viscous liquid, and under the joint action of temperature and pressure, the resin will produce volume shrinkage at high temperature[1,2]. After the gel point, the cross-linking reaction will appear, then the resin began to produce internal stress. If the FBG sensors were embed, because of the strain optic effect, the wavelength of the optical grating will be offset, and the achieved monitoring signal will be able to reflect the internal stress of the resin and the development process accordingly[3]. In the cooling stage, when the temperature is reduced to the initial temperature, the resin will gel shrinkage, and the internal stress is mainly due to glass shrinkage[4]. The embedded FBG sensor wavelength offset can reflect the residual deformation of the composite parts[5]. Therefore, FBG sensor is a viable mean of monitoring composite material thermal curing process.

2. Experimental work
The FBG sensors used in the experiment were made on ordinary quartz fiber, and the 125μm diameter single-mode fiber was used. The sensing grating length is 5mm, the central wavelength are 1541nm, 1550nm, 1555nm separately, the reflectivity is more than 99%, and the center distance of the two grating is 8cm. The composite materials used in the experimental is the high-strength II glass fiber / 4304 epoxy resin.

The single layer wound prepreg was cut into 6 cm x 6 cm squares, and the FBG sensor was embeded between 7 and 8 layer according to [0/90] 15s ply. The fiber was laid on the unidirectional layer of the dry yarn, as shown in Figure.1. The outlet of the fiber was protected by a welded bushing. The composite plate was sandwiched between two aluminum plates and all were placed in a thermosetting chamber. A 15 kg weight was used to provide a curing pressure of about 0.4 MPa.
Figure 1. Unidirectional layer of the glass fiber laying with optical grating.

The sensor spectra were recorded using SM 125-500 fiber grating demodulator, and the FBG sensor was calibrated for temperature and strain coefficients before the thermal curing monitoring test. The resin in the critical state has a certain viscosity, when the sensors were embeded in the composite material layer, there will be quasi-residual stress. In order to avoid this situation, the sensor need to be slightly pulled, so that it is in a stretched state.

3. Results and discussion

Usually, for the prepreging strap composite structure, its thermal curing process include three stages: the heating process, insulation/curing process and cooling process. During the experiment process, the SM125 demodulator can record the optical grating response of the entire curing process, and the response of the reference optical grating and the embeded grating is shown in Figure 2.

Figure 2. Optical grating response during curing process.

The composite laminates used in the experiment are relatively thin, the volume is relatively small and the distribution is relatively uniform. It can be seen from Figure 2 that the response of the reference sensor and the embeded sensor is nearly same in the temperature raising and curing/curing stages. In the cooling stage, under the joint effect of temperature drop and resin shrinkage, the reference FBG sensor and the embedded FBG sensor shows a large difference. The temperature change curves of the curing process recorded by the reference FBG sensor and the embedded FBG sensor are shown in Figure 3.

Figure 3. Temperature change curves during curing process.
As can be seen from the Figure.4, the temperature of the reference optical grating is very accordant at the heating stage, but there is a slight lag in the curing stage. This hysteresis error is likely to due to the experimental device itself, and the process of cooling is similar. The resin viscosity change curve throughout the curing process is shown in Figure.4.

![Resin viscosity change curve during curing process](image)

**Figure.4** Resin viscosity change curve during curing process

Since the resin viscosity drastically decreases at the beginning of the curing process, the logarithm coordinate is used in Figure.4. The resin viscosity changes relatively slowly during the incubation/curing phase. The internal stress response measured by embedded FBG sensor is shown in Figure.5.

![The internal stress curve during curing process](image)

**Figure.5** The internal stress curve during curing process

It can be seen that the temperature rise from room temperature to 130°C, with the temperature rising, the resin melt quickly from the B-stage, the viscosity dropped sharply until to the lowest point at about 64°C. As can be seen from Figure.5, the strain value measured by the FBG sensor is gradually decreased. The reason is that the resin is softened again from the critical solid state until to the viscous liquid state, and the tension of the optical grating in the embedded stage is gradually released.

In the curing stage, the resin present complex physical and chemical changes, and the resin viscosity rise slowly with the prolonging of the curing time. This process can be divided into two stages of B1 and B2, and in the B1 stage, the resin melted completely, and then began to curing reaction, the resin viscosity gradually increased. With the reaction progresses, the resin at the boundary of the laminate was extruded out under the pressure, and then the resin at the center begins to flow to the boundary region, and the stress in the resin where the optical grating was embedded begins to increase. Along with the curing process, the resin viscosity increases gradually, and the resin distribute gradually more symmetrical under the action of pressure, at the same time, the measured optical grating strain also maintain nearly in a stable value.

In the cooling stage, before the temperature dropping to the glass transition temperature point (the 2 point), the curing material component is in the cooling shrinkage (or physical contraction) stage, and the optical grating excursion caused by resin flowing disappear rapidly, or even turn into the contraction state. From a macroscopic point of view, the strain measured by the FBG sensor becomes smaller as the temperature decreases. However, from the microscopic point of view, the resin around the optical grating begins acting on the grating, and produces non-uniform stretching or compression, at the mean time, the FBG sensor reflection spectrum appear distortion and degradation. The
experiment results shown that the internal stress is mainly caused by the glassy conformation, and the wavelength offset of the FBG sensor reveals the residual deformation of the cured composite material.

4. Conclusion
It can be seen from the experiment that the FBG sensor can monitor a variety of different physical parameters at all stages of the thermal curing process, and this method can accurately reflect the change state of the resin in each stage of curing. It shows that the FBG sensor can be applied to monitor the thermal curing process of the composite structure.

References
[1] A. Przekop, Warping of Stiffened Composite Panels Due to Temperature Changes in the Curing Process 56th AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference 5-9 January 2015, Kissimmee, Florida AIAA 2015-1433.
[2] A. Nobili, C. Signorini, On the effect of curing time and environmental exposure on impregnated Carbon Fabric Reinforced Cementitious Matrix (CFRCM) composite with design considerations, Composites Part B 112 (2017) 300-313.
[3] F.H. Guo. Key techniques in health monitoring system for solid rocket motor based on fiber bragg gating sensors, PhD Thesis, Xi’an hi-tech institute, Xi’an, PRC, 2008, pp26.
[4] X. Y. He. The research of composites structure damage detection for solid rocket motor based on embedded fiber bragg grating sensors, PhD Thesis, Xi’an hi-tech institute, Xi’an, China, 2011, pp10.
[5] Q. L. Anhduong, L. Z. Sun. Detectability of delaminations in solid rocket motors with embedded stress sensors, J. Propu and Pow, 29(2013) 299-304.