Load-sensitivity of Part-overlapped Carbon Fiber Polymer-matrix Smart Composite

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Introduction

An emerging and attractive method of strain sensing involves using the structural material itself as the sensor. The ability of materials to sense their own strain has been reported in continuous carbon fiber polymer-matrix composites [1-3]. The self-sensing ability in these composites is based on load-sensitivity, in which the material resistivity changes reversibly with strain. Gage factor, is the most important factor for the sensitivity. However, although continuous carbon fiber polymer-matrix composite is considered to be the dominant advanced lightweight structural material, due to its combination of high strength, high modulus of elasticity and low density, its gage factor is much lower than that of the composite with short cut carbon fibers, which has lower mechanical properties [4,5]. A new type CFRP smart material with higher gage factor (compared with continuous carbon fiber polymer-matrix composites) and higher mechanical properties (compared with short cut carbon fiber polymer-matrix composites) was developed by effectively overlapping uniaxial continuous carbon fibers in local area in epoxy resin matrix. Uniaxial tension and three-point bending experiments were applied to investigate the load-sensitivity of the part-overlapped carbon fiber polymer-matrix composite after attaching it to the surface of the FRP bars.

The Project of National Natural Science Foundation of China (No.50878169) supported this work.

Experimental

Specimen preparation

As described in the Fig.1, with a lay-up process, in the epoxy (E-44) matrix, two continuous carbon fiber bundles (TC12K35, PAN-based) in the single direction were attached to the surface of 300 × 20 × 4 mm FRP bar with a 30mm long overlapped part. An amine hardener (Polyamide resin) was used as a curing agent with the resin/curing agent weight ratio of 100/100. The cure was performed at 80℃ for 2 hours.

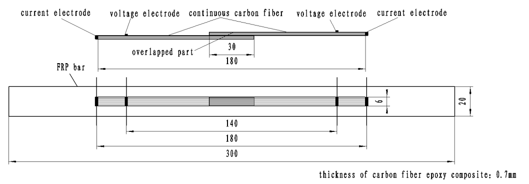

Fig.1: FRP specimen attached by part-overlapped carbon fiber polymer-matrix composite

In order to make a comparison, continuous carbon fiber polymer-matrix composites attached to the FRP specimens were also prepared by the same procedure.

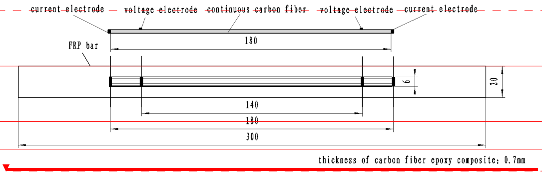

Fig.2: FRP specimen attached by continuous carbon fiber polymer-matrix composite

Measurement

The resistances were measured using the four-probe technique, with two outer probes (containing the fibers ends) introducing a constant current of 1 mA into the composite, and two inner probes (on the fibers surface, 140mm apart) measuring the potential difference. The resistances were obtained following the Ohms law. Silver paint was used in the electrodes preparation.

Cyclic tension in the fiber direction and cyclic three-point bending tests applied on the FRP specimens were conducted on Instron 5882 both with a frequency of 1/60 Hz. The three-point bending tests were with a span of 200mm and included two conditions: the smart composite was on the tensioned surface and the smart composite was on the compressed surface.

Result and discussion

In the tension test, as shown in Fig.3, load-sensitivity was found in part-overlapped carbon fiber polymer-matrix composite, in which the resistance increased linearly and reversibly with the increase of the tensile strain, just as the property of continuous carbon fiber polymer-matrix composite described in Fig.4.

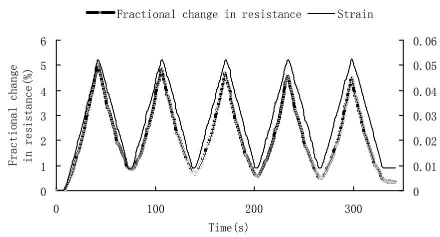

Fig. 3: Fractional change in resistance of part-overlapped carbon fiber polymer-matrix composite vs. time and strain vs. time (thin curve) during the cyclic tension test

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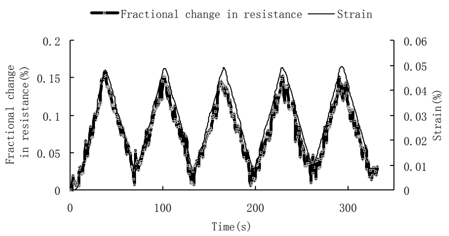

Fig. 4: Fractional change in resistance of continuous carbon fiber polymer-matrix composite vs. time (thick curve) and strain vs. time (thin curve) during the cyclic tension test

Load-sensitivity is usually characterized by the gauge factor (GF), defined as the fractional change in resistance per unit strain. The results show a GF of 104 for part-overlapped carbon fiber polymer-matrix composite, much bigger than that of continuous carbon fiber polymer-matrix composite, which was only 2.6. Furthermore, such a big GF weakened the noise effect, making the resistance response more stable.

Three-point bending tests revealed that for the part-overlapped carbon fiber polymer-matrix composite, the load-sensitivity occurs in both tensioned condition and compressed condition, in which the resistance increases reversibly upon tension and decreases reversibly upon compression, as in Fig.5 and Fig.6.

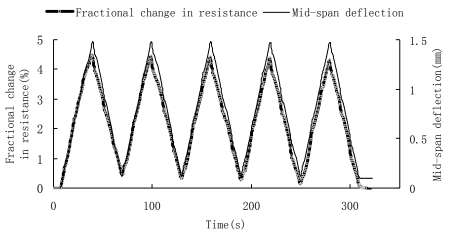

Fig. 5: Fractional change in resistance of part-overlapped carbon fiber polymer-matrix composite vs. time (thick curve) and mid-span deflection vs. time (thin curve) during the cyclic three-point bending test when it was on the tensioned surface.

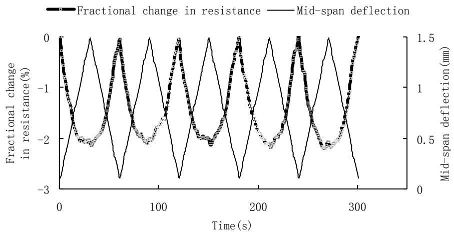

Fig. 6: Fractional change in resistance of part-overlapped carbon fiber polymer-matrix composite vs. time (thick curve) and mid-span deflection vs. time (thin curve) during the cyclic three-point bending test when it was on the compressed surface.

With the same deflection occurred, the absolute value of fractional change in resistance was smaller in the compressed condition, probably half of that in the tensioned condition, but still indicating a large GF.

The measured resistance of part-overlapped carbon fiber polymer-matrix composite can be modeled by the equivalent electrical circuit shown in Fig. 7. R_a and R_b are the longitudinal resistance of the un-overlapped parts. r_i (i=1~n+1) are the interfacial contact resistances in the overlapping area, and R_i (i=1~2n) are the sections of longitudinal resistance of overlapped parts.

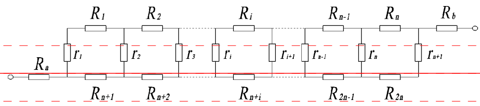

Fig. 7: Equivalent electrical circuit of part-overlapped carbon fiber polymer-matrix composite resistance

Because of the anisotropic resistivity, the measured resistance is dominated by t r_i, which depended on the interfacial fiber-fiber contacts associated with the fiber waviness Such a waviness diminishes when tensile strain in the fiber direction occurs, so that the number of r_i descends but their values increase, both of which could induce the measured resistance increase and cause a big GF.

Conclusion

1. Load- sensitivity was found in part-overlapped carbon fiber polymer-matrix composite, with the GF much bigger than that of continuous carbon fiber polymer-matrix composite.
2. An electrical model was set up to explain the load-sensitivity of part-overlapped carbon fiber polymer-matrix composite, induced by the change of the interfacial contact resistances.

References

1. D.D.L. Chung. Self monitoring structure materials. Materials Science and Engineering, 1998, 22(2):57-78
2. Shoukai Wang, D.D.L. Chung. Piezoresisitivity in continuous carbon fiber polymer-matrix composite. Polymer Composites, 2000, 21(1): 13-19
3. Sirong Zhu, D.D.L. Chung. Analytical model of piezoresistivity for strain sensing in carbon fiber polymer–matrix structural composite under flexure. Carbon, 2007, 45(8): 1606-1613
4. N. Angelidis, C.Y. Wei and P.E. Irving, The electrical resistance response of continuous carbon fibre composite laminates to mechanical strain, Compos: Part A 35 (2004): 1135–1147
5. Xiaojun Wang and D.D.L. Chung, Short Carbon Fiber Reinforced Epoxy as a Piezoresistive Strain Sensor, Smart Mater. Struct. 4 (1995)., 363-367

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A commercially available continuous carbon fiber bundle (pan-based, ???TEX,) was used in this study. First of all, the carbon fiber bundle was cut into 105mm long specimens[U1], then two electrodes were pasted by the silver paint in the configuration that one was at the end containing the fiber ends and the other one was on the fiber surface 20mm apart from the former one. After the silver paint cured, two carbon fiber specimens were attached on the 300.0 x 20.0 x[U2] 4.0 mm FRP bar surface in sequence with a lay-up process in the epoxy resin matrix (E44, Yueyang Epoxy Company Ltd. P.R.C). The two attached carbon fiber bundles were in the single direction but had a 30mm long overlapped part, as described in the Fig.1. As recommended by the manufacturer, an amine hardener (Polyamide resin, Xiangtan Chemical Reagent Plant P.R.C.) was used as a curing agent with the resin/curing agent weight ratio of 100/100. The specimens were cured at room temperature for 24 hours, and the post cure of the composites was performed at 80℃ for 2 hours.

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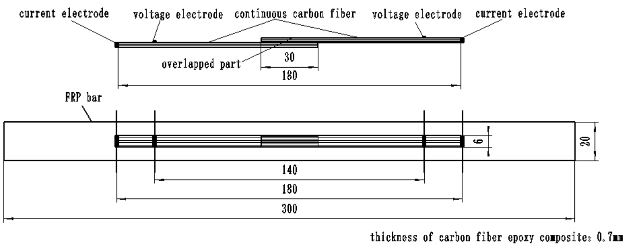
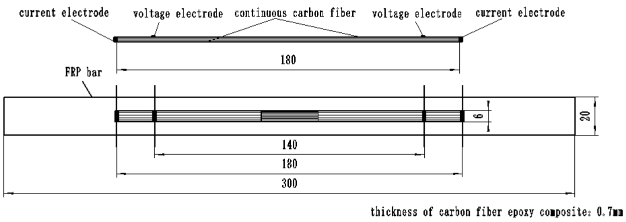


Fig.1: FRP specimen attached by part-overlapped carbon fiber polymer-matrix composite



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In the tension test the load amplitude was 800N.

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In both two conditions the span length was 200mm, and the amplitude of the mid-point deflection was 1.5mm.

In each test, the resistance changes were measured using the four-probe thenique, with two outer probes introducing a constant current of 1 mA into the composite, and two inner probes measuring the potential difference. The resistances were obtained following the ohms law.

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Fig.3 and Fig.4 respectively show the fractional change in resistance of part-overlapped carbon fiber polymer-matrix composite and continuous carbon fiber polymer-matrix composite when the attached FRP specimens were in the cyclic tension.

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As in Fig.3, load-sensitivity was found in part-overlapped carbon fiber polymer-matrix composite, in which the resistance increased linearly and reversibly with the increase of the tensile strain, just as the property of continuous carbon fiber polymer-matrix composite described in Fig.4,

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$$GF = \frac{\Delta R}{R_0 \varepsilon} \quad (1)$$

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, indicating that part-overlapped carbon fiber polymer-matrix composite is much more sensitive to strain in the fiber direction

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Fig.5 and Fig.6 show the fractional change in resistance of part-overlapped carbon fiber polymer-matrix composite when the attached FRP specimens were in the cyclic

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. Fig.5 is in the condition that the carbon fiber composite was on the tensioned surface, and Fig.6 is in the condition that the carbon fiber composite was on the compressed surface.

Fig.5 and Fig.6

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the load-sensitivity could be found

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When the same mid-span deflection occurred, in the compressed condition, the absolute value of fractional change in resistance was smaller, probably half of that in tensioned condition, but still indicating a large GF.

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The .change of the interfacial contact resistances is the origin of its sensitivity.

页 2: [32] 带格式的 USER 2009-6-8 20:22:00

字体: 11 磅

页 2: [32] 带格式的 USER 2009-6-8 20:22:00

字体: 11 磅

页 2: [32] 带格式的 USER 2009-6-8 20:22:00

字体: 11 磅, 非加粗, 非倾斜

页 2: [32] 带格式的 USER 2009-6-8 20:22:00

字体: 11 磅

页 2: [32] 带格式的 USER 2009-6-8 11:06:00

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页 2: [33] 删除的内容 USER 2009-6-8 11:01:00

Plots of f

页 2: [33] 删除的内容 USER 2009-6-8 16:16:00

strain

页 2: [34] 删除的内容 USER 2009-6-8 20:54:00

Acknowledgement

The Project of National Natural Science Foundation of China under grant No.50878169 supported this work.

页 2: [35] 带格式的 USER 2009-6-8 15:37:00

字体: 11 磅, 字体颜色: 自动设置

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页 2: [36] 带格式的 USER 2009-6-8 15:37:00

缩进: 左侧: 0 厘米, 编号 + 级别: 1 + 编号样式: 1, 2, 3, … + 起始编号: 1 + 对齐方式: 左侧 + 对齐位置: 0.63 厘米 + 制表符后于: 1.27 厘米 + 缩进位置: 1.27 厘米, 制表位: 1.5 字符, 列表制表位 + 不在 3 字符

页 2: [37] 删除的内容 USER 2009-6-8 15:35:00

Sihai Wen, D.D.L. Chung,Carbon fiber-reinforced cement as a strain-sensing coating. Cement and Concrete Research. 2001,31:665-667

Shoukai Wang, D.D.L. Chung, Jayceeh. Chung. Self-sensing of damage in carbon fiber polymer–matrix Composite Cylinder by Electrical Resistance Measurement. Journal of Intelligent Material Systems and Structures, 2006, 17(1): 57-62

页 2: [38] 带格式的 USER 2009-6-8 15:41:00

缩进: 左侧: 0 厘米, 编号 + 级别: 1 + 编号样式: 1, 2, 3, … + 起始编号: 1 + 对齐方式: 左侧 + 对齐位置: 0.63 厘米 + 制表符后于: 1.27 厘米 + 缩进位置: 1.27 厘米, 制表位: 1.5 字符, 列表制表位 + 不在 3 字符

页 2: [39] 带格式的 USER 2009-6-8 21:12:00

字体: (默认) Times New Roman

页 2: [40] 带格式的 USER 2009-6-8 15:41:00

字体: 11 磅, 无下划线

页 2: [40] 带格式的 USER 2009-6-8 15:41:00

字体: 11 磅

页 2: [40] 带格式的 USER 2009-6-8 15:41:00

字体: 11 磅

页 2: [41] 删除的内容 USER 2009-6-8 15:38:00

页 2: [42] 带格式的 USER 2009-6-8 15:41:00

字体: 11 磅

页 2: [42] 带格式的 USER 2009-6-8 15:41:00

字体: 11 磅

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