FRPRCS-14, Belfast - June 2019

Performance of Solar Cells Integrated with Fiber-Reinforced Polymer-Confined Concrete Beams under Bending Load

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Abstract

Renewable solar energy has been increasingly used due to its efficiency and cleanliness. Attaching solar cells directly to supporting structures, such as building roofs, can eliminate mounting systems and their associated cost. Once the mounting systems are eliminated, solar cells and the supporting structures become an integral part, which is subjected to the same strain. Therefore, it is necessary to study the performance of solar cells under different strain states. In this study, amorphous silicon solar cells (a-Si) were attached to Fiber-Reinforced Polymer (FRP)-confined reinforced concrete beams to evaluate their performance under bending load. Two groups, with four specimens for each group, were tested using different test setup to introduce tensile or compressive stresses to the solar cells. In all tests, loads, displacement, strains, and current density-voltage (J-V) curves were recorded and Maximum Power Point (MPP) were calculated. It was concluded that the specimens in both groups assumed linear behaviour and the performance of the (a-Si) solar cells remained unchanged until the specimens failed. Therefore, the solar cells can function well when they are integrated with bending members using FRP materials.

Keywords: Solar cell performance, FRP-confined concrete beam, bending test, J-V curve, Maximum Power Point

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Introduction

Attaching solar cells directly to supporting structures can eliminate the mounting systems and reduce the cost. It follows that solar cells and the supporting structures will be subjected to the same stain. Therefore, it is necessary to study the strain effect on the performance of solar cells under different loading conditions. Chen et al. [1] studied the strain effect on the performance of solar cells under both compression and tension. Some supporting structures, such as building roofs, will take bending load. Therefore, the objective of this paper is to study the performance of solar cells when their support structures are subjected to bending load.

Test Specimens

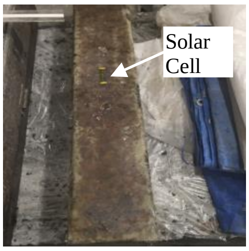
Eight Fiber-Reinforced Polymer (FRP)-confined reinforced concrete beams with a cross section of 152 mm x 152 mm (6 in. x 6 in.) and a length of 914 mm (36 in.) were constructed and divided evenly into two groups, where solar cells were subjected to either compressive (Group I) or tensile (Group II) stresses. The 28-day compressive strength of the concrete was 41.3 MPa (6 ksi). Steel rebars were ASTM A615 Grade 60 steel, with a yield strength of 414 MPa (60 ksi). For FRP materials, the fiber used in the experiment was Chopped Stand Mat (CSM) and the epoxy was 404-isophthalic resin, similar to those used by Petersen et al. [2] and Yossef et al. [3]. FRP shell was pre-manufactured and amorphous silicon (a-Si) solar cells were glued to the shell using epoxy during the fabrication process. Aggregates were added to the interior surfaces of the FRP shell to ensure strong bonding between FRP and concrete. Concrete was cast in the shell so that three sides of the beams were confined by FRP, as shown in Figure 1a.

Test Setup

A photo of the test setup is shown in Figure 1b. Figure 2 describes the setup details for Groups I and II. A frame holding two actuators was constructed. Eight strain gauges were installed at the FRP and concrete surfaces for each specimen. Four deflection transducers were installed to measure the beam deflections at the mid-span and under the loading points. Two load cells were placed at supports to measure the applied load. Two halogen lamps (Philips 13117) with 150 W were installed to illuminate the solar cells, as shown in Figure 1b. To eliminate excessive temperature generated from the halogen lamps, three fans close to the lamps were supported by an aluminium plate.

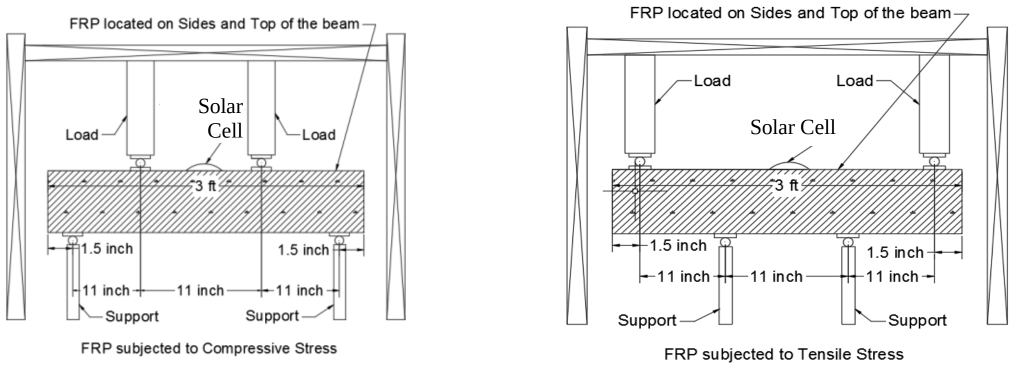
Test Procedures

The specimens were tested according to ASTM standard [4]. Loads, strains, and deflections were recorded using a data acquisition (DAQ) system. The performance of the solar cells was measured using J-V (current density-voltage) characteristics data obtained from the source-meter connected to the amorphous silicon solar cell at different displacements.



. (a) Test Specimen (b) Photo of Test Setup

Figure 1: Test Specimen and Setup



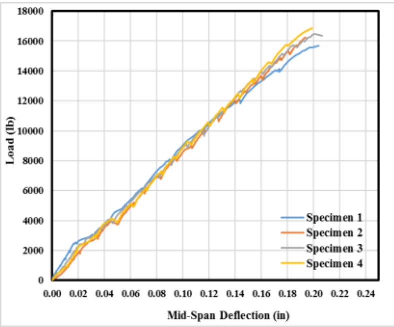
(a) Group I Test Setup (b) Group II Test Setup

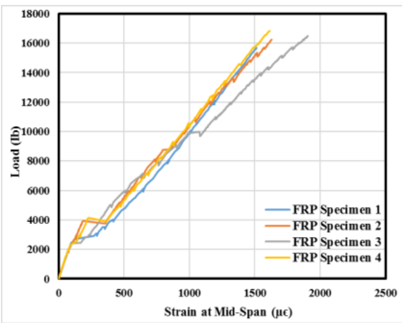
Figure 2: Test Setup (1 in.=25.4 mm)

Test Results

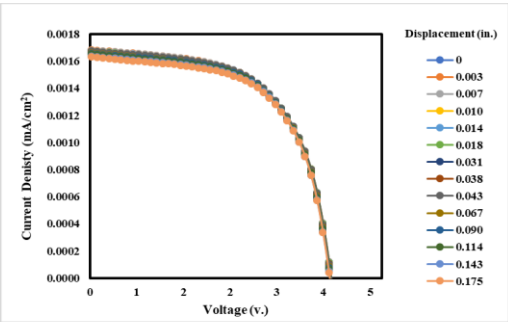
Group I

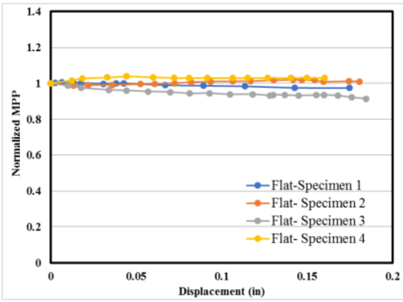
The load-displacement and load-strain at mid-span curves are plotted in Figures 3a and 3b, respectively. It can be seen from these figures that top concrete was subjected to compression. The specimens performed similarly and assumed linear behaviour until failure, with the maximum displacement of 5.1 mm (0.2 in.) and strain of 0.16% at the mid-span. The failure mode was the cracks occurring at only the bottom surface of the concrete, followed by the debonding of FRP under the applied load. No debonding of the (a-Si) solar cell was observed during the test. Figure 3c illustrates J-V curves of the solar cell for the first specimen at different displacement levels. Maximum Power Point (MPP) was calculated based on the J-V curves. Figure 3d displays MPP vs. displacement curves. It can be seen from Figures 3c and 3d that the performance of the solar cells remained almost constant during the test until they failed. Detailed results can be found from Alateeq [5].





(a) Load-Disp. Curve (b) Load-Strain Curves



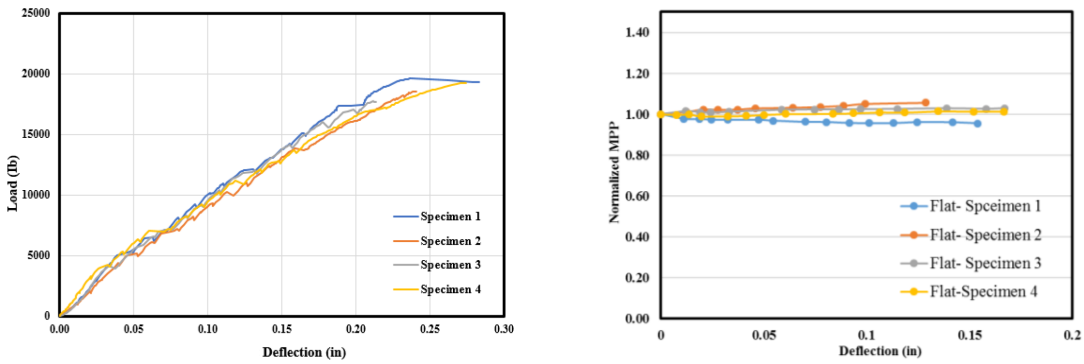


(c) J-V Curves at each Displacement (d) Normalized MPP-Disp. Curve

Figure 3: Group I Test Results (1 in.=25.4 mm; 1 lb=4.4482 N)

Group II

The load-displacement and normalized MPP-displacement curves are plotted in Figures 4a and 4b, respectively. Similar to specimens in Group I, the specimens in Group II assumed linear behaviour until failure, with the maximum displacement of 6.1 mm (0.24 in.) and strain of 0.8% at the mid-span. The performance of the solar cells remained almost constant until the specimens failed.



(a) Load-Dipl. Curves (1 lb=4.4482 N) (b) MPP-Disp. Curves (1 in.=25.4 mm)

Figure 4: Group II Test Results

Conclusions

Amorphous silicon solar cells were attached to FRP-confined reinforced concrete beams to study the effect of the bending load on the performance of the solar cells when subjected to both compression and tension stresses. It can be concluded that the beams assumed linear behaviour and the performance of the solar cells remained unchanged until the specimens failed. Therefore, solar cells can function well when they are integrated with bending members using FRP materials.

References

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