Executive Summary

Evaluation of the Origami Solar Steel Frame for PV Modules

TECSI Solar was contracted by Origami Solar to test their production quality steel frames. TECSI Solar conducted extensive testing on several Origami Solar steel frame designs to determine the feasibility of replacing the typical aluminum (AL) extruded frame of a solar panel with a roll-formed steel alternative.

Edge Protection

Solar module frame walls protect the laminate edge, provide a mounting means to secure the module to a support structure, and provide structural rigidity to protect the laminate. All investigated designs closely mirrored the general shape of traditional aluminum frame walls including the laminate cavity. Thus, the laminate edge protection of the Origami steel frame design is considered by this office to be equivalent to traditional aluminum frames and the overall shape is considered a direct replacement from a module manufacturer's perspective.

Compression Strength

The basic frame design was tested for compression strength to ensure it could withstand typical top clamp loads which could result in frame buckling or laminate breakage. The frames were found to be sufficiently rigid providing a high level of stiffness and stability. See Figure 1.

Mounting Slot

Aluminum framed modules typically have mounting slots as large as 9mm x 14mm for mechanical attachment to a support structure. This slot size was tested and found to be sufficient to develop 150 psf of module uplift with the steel frames. In addition, it was found to perform similarly to a 9mm hole. See Figure 2. For full scale mechanical load testing, discussed further on in this report, the slots for the steel frame were changed to 7.4mm x 14mm, closely matching the mounting slots on the provided AL frames allowing equivalent comparisons in performance.

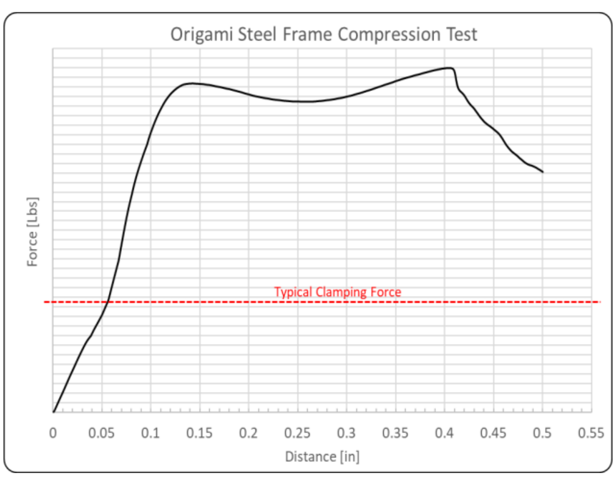

Figure 1 – Compression Test

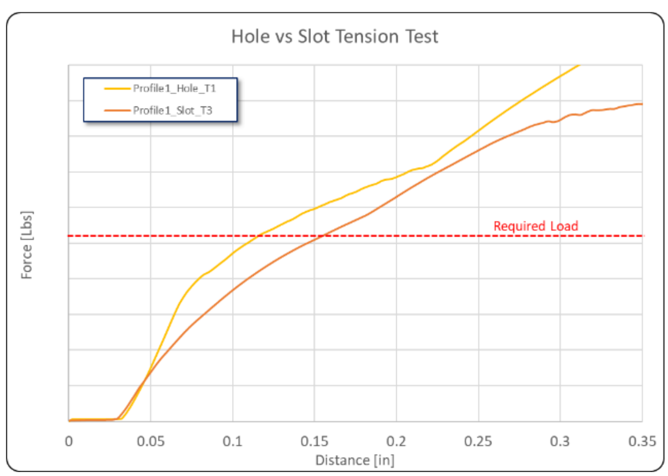

Figure 2 - Hole vs Slot

Importance of Frame Wall Rigidity

The frame wall of a solar panel provides rigidity to the laminate. This rigidity protects the internal electrical components of the laminate by reducing the stresses from deflections caused by external loads. Therefore, the greater the rigidity of the frame the better it protects the solar cells and their electrical connections. Traditionally, increased system rigidity has been achieved by increasing the frame height or through a more distributed support structure. Results from mechanical load testing of the Origami modules provides evidence that using steel for the frames could break this paradigm by creating increased system rigidity without changing the frame height or support structure. This is made possible by, (1) the strength of the roll-formed steel exceeded that of aluminum typically used in standard PV modules by 2X, and by (2) the higher modulus of elasticity (resistance to bending) of steel which is roughly 3X more than aluminum. The Origami steel frame substantially outperformed the taller aluminum frame in the 1/5th bolt connection testing, meaning that electrical components of the PV laminate are better protected by the Origami Solar steel frame.

Mechanical Load Testing - Materials

Origami Solar provided this office with production quality frames of roll-formed steel and a module manufacturer provided aluminum extruded frame walls and fully functional PV laminates. TECSI transformed the roll formed steel frame components into module frames by matching the length and bolt slot locations of the aluminum frames. The steel frame walls were then assembled onto the laminates at the TECSI Solar facility using industry standard silicone RTV adhesive and following TECSI Solar's standard assembly practices. All modules were allowed to cure for a minimum of 5 days prior to testing. The testing program compared the 35 mm tall steel frame against the 40 mm tall aluminum frame using identical PV laminates.

Mechanical Load Testing – Setup and Test Configurations

The Origami Solar and typical aluminum framed modules were tested with 1/5 point bolted strut-rail connection; Figures 3 & 4. Testing was conducted in both the up and down orientations with deflection measurements and electroluminescence (EL) images taken at 5 psf increments. The center of the laminate was measured along with the center of the long frame wall. Measurements were auto recorded using digital indicators and measurement repeatability was verified as ±1/16". Virgin modules were used for each test configuration with weight evenly distributed in 25 lb. increments. Maximum test load was 150 psf.

Figure 3 – Strut-Rail 1/5th Steel Frame

Figure 4 – Strut-Rail 1/5th AL Frame

Mechanical Load Testing – Results from 1/5 Strut-Rail Configuration

Downforce Test

The deflection measurements for the 1/5th strut-rail configuration in the down direction showed that the 35 mm Origami steel framed module performed similarly to the standard 40 mm AL framed module. See Figure 5. However, the AL framed module had a deflection direction changed during testing after 75 psf. This is evidence that the AL frame provided less stability than the Origami steel frame. In the following figures, the typical AL framed module is shown in red, and the Origami steel framed module is shown in blue.

Upforce Test

The Origami steel and standard AL framed modules performed similarly in the upforce direction to 80 psf as shown in Figure 6. However, at 85 psf the aluminum frame failed simultaneously at all 4 bolted connections. See Figure 7. The Origami steel framed module continued to withstand its load all the way to 135 psf where it finally failed from buckling near the strut location.

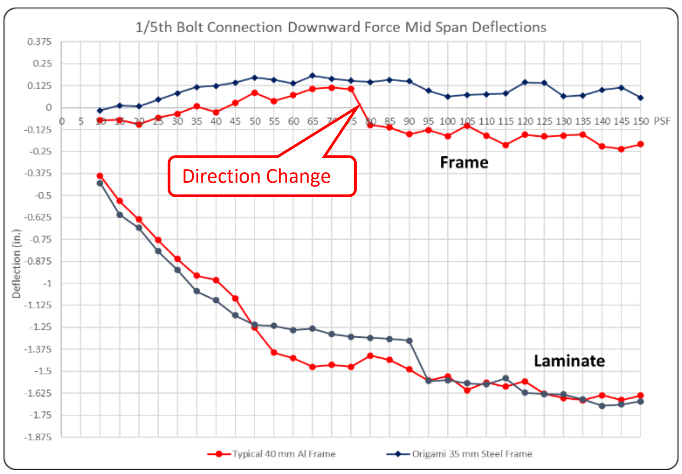

Figure 5 – 1/5th Strut-Rail Downforce Deflection Results

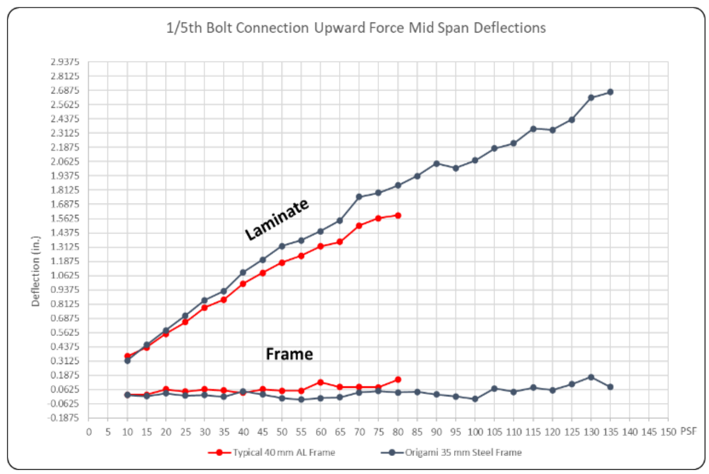

Figure 6 – 1/5th Strut-Rail Upforce Deflection Results

Figure 7 – 1/5th Strut-Rail Upforce Bolt Hole Locations at Max PSF

Electroluminescence Testing

When current passes through PV cells, light emission occurs. This phenomenon is called electroluminescence, EL. EL imaging can be used to detect hidden defects in the structure of PV cells such as cracks caused by manufacturing, shipping and handling, installation, and environmental stresses. Cracks in the cells of a module can lead to poor electrical performance as well as an increase in cell temperatures that in extreme cases can lead to module failure.

EL imaging showed that the steel framed module did a significantly better job at protecting the cells in the laminate in the downforce configuration. See Figure 8. The Origami steel framed module remained stable all the way to 150 psf resulting in only 1 cracked cell, which initiated at 145 psf. On the other hand, the AL frame underwent a deflection transition from concave to convex at 80 psf as shown in Figure 5, and produced a total of 8 cracked cells with the first crack initiated at 20 psf.

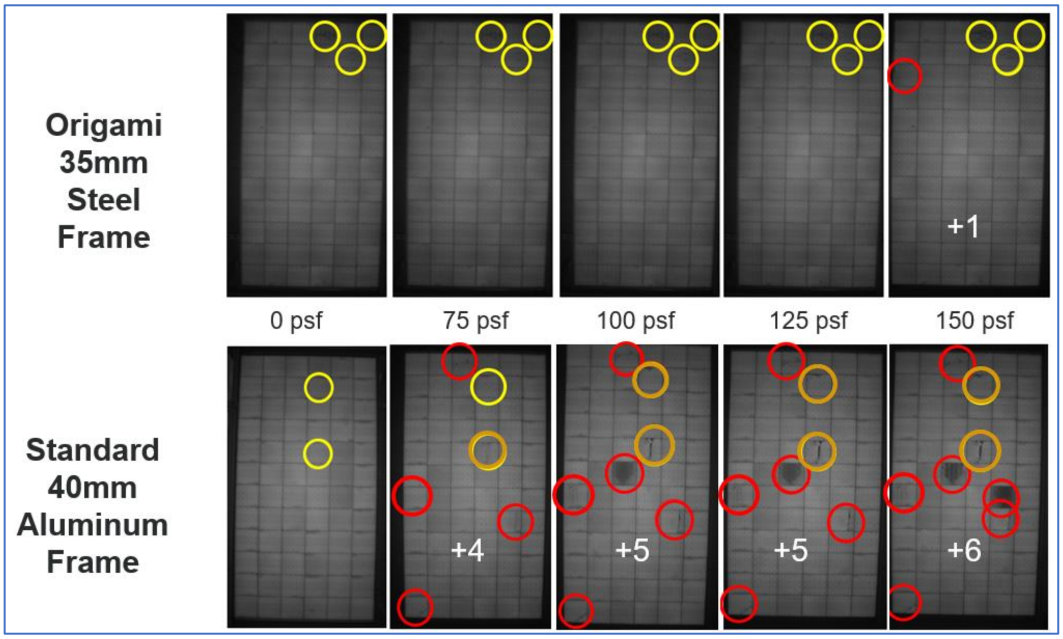

Figure 8 – 1/5th Strut-Rail Downforce EL Test Results

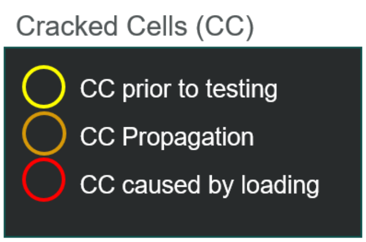

Figure 9 - EL Images Key

Loading	Propagated Fractures		New Fractures	
	Steel	AL	Steel	AL
0 psf	0	0	0	0
75 psf	0	1	0	4
100 psf	0	2	0	5
125 psf	0	2	0	5
150 psf	0	2	1	6

Figure 10 – Cracked Cell Summary

Conclusions and Recommendations

The Origami roll-formed steel frames proved to be overall resilient and able to surpass the performance of typical aluminum frames in many circumstances even though it was 13% shorter. In the areas where the Origami design did not perform as well, modest design changes can be deployed to improve performance bringing it more in line with expectations. In addition, the cross-sectional area can be modified in any number of ways to meet the needs of individual module manufactures. In summary, this office has concluded that the Origami steel frame has demonstrated it is a solid candidate for consideration to replace the extruded aluminum frames of PV modules.

Sincerely,

Samuel Truthseeker P.E.
Founder and Principal Engineer