Sorting test of bending load on the interconnector in crystalline silicon photovoltaic modules

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INTRODUCTION

Background : Han et al. reported that the ribbon cracks occupy about 8 % of all failure modes of photovoltaic (PV) modules in the field by the literature survey in 2012. The ribbon cracks mean that the current path is cut off and the power generation of PV modules is lost. However, thermal cycling (TC) test specified in IEC 61215 evaluates the failure of the soldering or the cell cracks, and cannot reproduce ribbon cracks.

Purpose : In this study, we tried to evaluate the sorting test for the breakage of ribbon for extracting the weak point or the defect inherent in the modules.

MATERIALS AND METHOD

Figure 1. Photographs of load cycle bending machine.

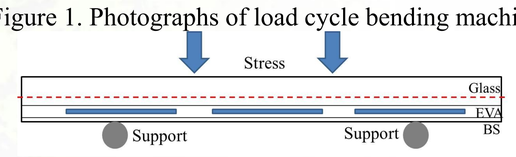

Figure 2. Images of 4 point stress.

Table 1. Specifications of materials used in PV module.

Material	Specification	Supplier
Cell	Multicrystalline-Si cell (156 mm × 156 mm)	Q Cells
Glass	Semi-tempered glass	AGC
Encapsulant	EVA	Nondisclosure
Interconnector	A-SPS (Leaded, Ag)	Hitachi Cable
Back sheet	PVF / PET / PVF	Nondisclosure
Size	540 mm × 200 mm × 4 mm	-

Figure 3. Photograph of PV module sample.

Table 2. Test conditions.

Stress	500 N
Bending / unbending	4 s / 4 s
Bending cycle	10,000 times each test
Temperature	-20℃ / 25℃ / 80℃

SIMULATION

Table 3. Materials properties used in simulation at 23°C.

	Unit	Glass	Silicon	EVA	PET	Copper	Solder	Ag
Young's modulus	Pa	7.31E+10	1.31E+11	1.68E+07	1.60E+06	1.30E+11	2.20E+10	8.27E+10
Poisson's ratio	-	0.22	0.27	0.45	0.33	0.34	0.37	0.37
Thermal expansion coefficient	1/°C	9.03E-06	4.15E-06	2.70E-04	2.50E-05	1.70E-05	2.40E-05	1.93E-05
density	g/cm³	2.5	2.33	0.95	1.4	8.96		10.49

Table 4. Young's modulus of EVA.

Temperature (°C)	-20	23	80
Young's modulus (Pa)	1.40E+08	1.68E+07	1.03E+06

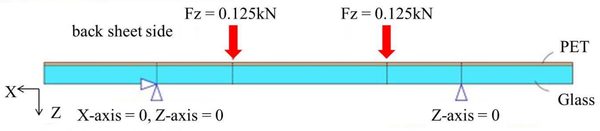

Figure 4. Boundary condition of simulation.

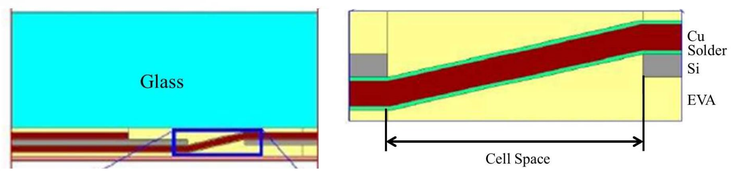

Figure 5. Cross section of model.
Cell space was modified from 1 mm to 5 mm at each simulation.

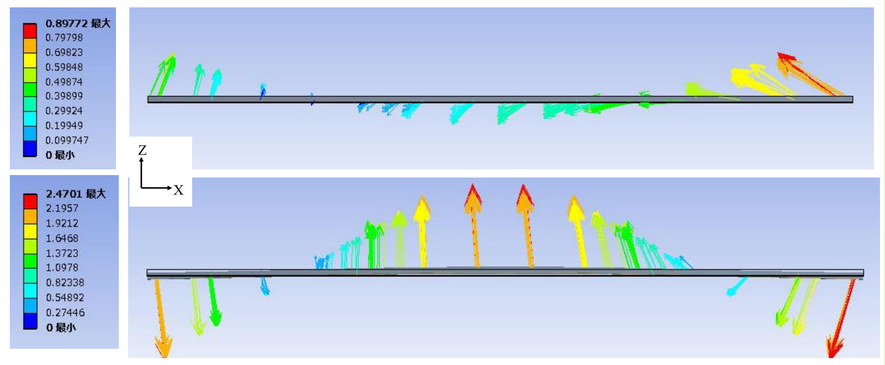

Figure 6. Results of FEM simulation of thermal stress and bending load from back sheet side at -20°C. Displacement was dominated by bending load.

RESULTS & DISCUSSION

	EL initial	EL after test	I-V	Ribbon Break
1 mm		10,000 cycles		○
2 mm		20,000 cycles		○
5 mm		20,000 cycles		○
10 mm		30,000 cycles		○

Figure 7. Results of 4 point load cycle bending test.

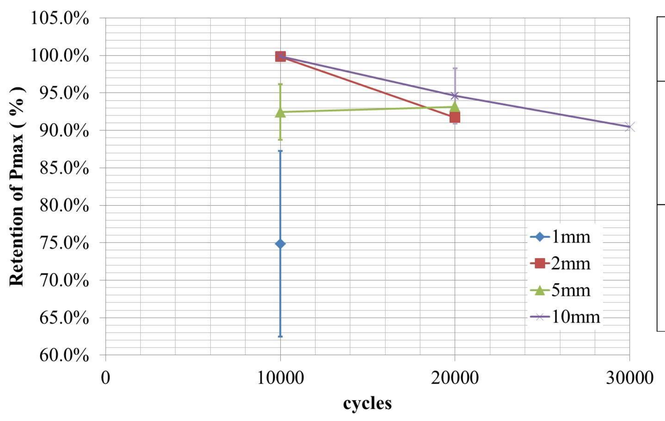

Figure 8. Retention of P_{max}.

Modules with the space	Microscope	Cross-section
1 mm		
2 mm		

Figure 9. Microscopic view and cross section image.

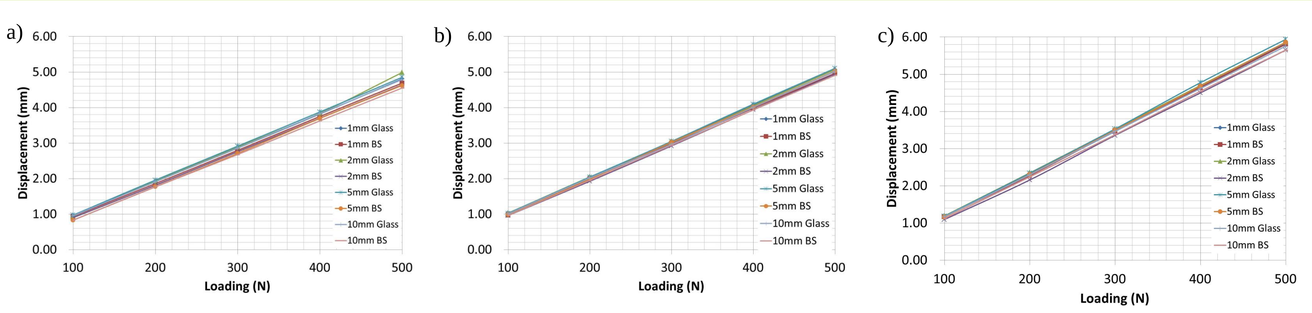

Figure 10. Results of displacement of module with each cell space.
a) -20°C, b) 23°C and c) 80°C .

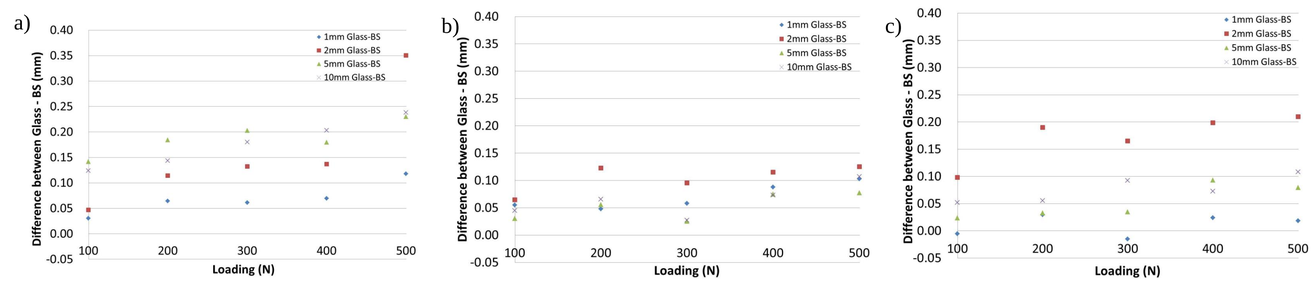

Figure 11. Results of difference between displacements by glass-side load and back-sheet-side load for each cell space.
a) -20°C, b) 23°C and c) 80°C.

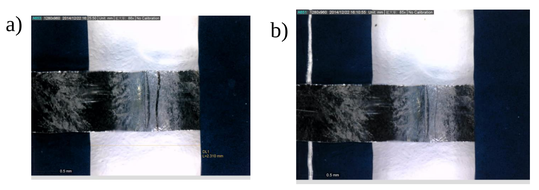

Figure 12. View of ribbon after test.
a) no bending and b) 500N.

Table 5. Results of measurement at cell space.

1 mm (mm)		2 mm (mm)		5 mm (mm)	
No bending	Bending	No bending	Bending	No bending	Bending
1.07	1.04	1.83	1.79	5.03	4.98
difference	0.03		0.04		0.05

Table 6. Comparison of displacement of modules between simulation and measurement.

	Simulation (mm)						Measurement (mm)		
Cell space	1 mm		2 mm		5 mm		1 mm	2 mm	5 mm
Tem perature	Only thermal stress	Bending load	Only thermal stress	Bending load	Only thermal stress	Bending load	Bending load		
-20	0.40	2.50	0.4	2.47	0.32	2.25	4.69	4.64	4.63
23	0.48	2.40	0.47	2.40	0.29	2.40	4.97	4.95	5.03
80	0.15	2.70	0.15	2.67	0.15	2.28	5.81	5.65	5.86

Table 7. Results of the maximum stress level of ribbon.

	Only thermal stress (MPa)			Bending load (MPa)		
	Cell space					
Temperature(°C)	1 mm	2 mm	5mm	1 mm	2 mm	5 mm
-20	1231.9	1231.1	920.4	1236.2	1199.8	1445.8
23	891.7	809.2	668.9	891.4	805.3	1188.5
80	493.8	476.0	365.5	1041.0	924.4	881.6

1. As a result of the bending load test using the test modules with various spaces between the cells, the maximum power (P_{max}) was decreased by about 25% for the module with the space of 1 mm. P_{max} was decreased by about 10% for the modules with the space of 2 mm, 5 mm and 10 mm and complete breakage of ribbon was observed (Figures 6, 7 and 8).
2. As a result of the displacement of module with each cell space, the displacement was proportionally increased with an increase in bending load and temperature. The highest displacement was about 6 mm by 500 N at 80°C. As a result of the difference between displacements by glass-side load and back-sheet-side load, displacement by glass-side load was larger than that from back-sheet-side load (Figures 10 and 11).
3. Cell space was contracted by bending load of 500 N (Figure 12 and Table 5).
4. FEM simulation underestimated the displacement of modules. Especially difference between displacements from simulation and measurement was larger over by 2 times. It was also found that displacement strongly depends on temperature only in the case of measurement (Table 6).
5. The maximum stress level of ribbon of bending load for cell space of 1 mm was the largest of all (Table 7).

SUMMARY

In this study, it was found that the space over 1 mm between the cells is needed for high reliability and the bending load test is useful for the evaluating test for the breakage of ribbon.

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