Presented at the 33rd European PV Solar Energy Conference and Exhibition, 25-29 September 2017, Amsterdam, The Netherlands

ANALYSIS OF PEEL AND SHEAR FORCES AFTER TEMPERATURE CYCLE TESTS FOR ELECTRICAL CONDUCTIVE ADHESIVES

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ABSTRACT: Soldering of copper ribbons on busbars is the standard process for the series interconnection of solar cells in industrial PV modules. As an alternative interconnection approach electrical conductive adhesives (ECAs) can be used for cell interconnection. ECAs are lead free and can be processed at temperatures below 200°C. However, the higher costs and the lower adhesive forces between interconnector and solar cell compared to established solder-based interconnection prevented a larger market share until now. We present results of 90° peel-tests according to DIN EN 61189-2:2006 and shear tests according to DIN EN 1465 for seven commercially available ECAs and a comparison to the electrical performance of corresponding 3-cell modules in the temperature cycle test according to IEC 61215. The results show that all samples pass the temperature cycle test with a loss of power below 5%. The measured peel forces decrease after TC600 whereas the shear forces remain at their initial level.
Keywords: PV Module, Interconnection Technologies, Electrical Conductive Adhesives, Reliability

1 INTRODUCTION

In the PV-industry, the mechanical quality of the interconnection between a solar cell and a ribbon is usually determined by a peel test. The recommended peel force is 1 N per mm ribbon width [3]. As an alternative to soldering, electrically conductive adhesives (ECAs) can be used for interconnecting the solar cells. The main advantages are that ECAs are lead free and the curing temperature is typically in a range between 140°C and 180°C. This makes ECAs a natural choice for temperature- or stress-sensitive cell structures (e.g. HJT). The main disadvantages are the costs, because usually ECAs are filled with silver, and the low adhesive forces achieved in the peel test [1, 2]. In this work we compare seven different ECAs in terms of the achieved adhesive forces in case of a 90° peel test. In addition, we introduce a shear test based on testing standard DIN EN 1465 [4]. The motivation of the shear test is that – once laminated - no loads perpendicular to the interconnection joint appear in a PV module. The results of the peel and shear tests are compared with the electrical performance of three cell modules which were subjected to the temperature cycle test [5]. The temperature cycle test is chosen due to thermomechanical stress that results from different CTEs of the materials (silicon, copper) and which directly affect the interconnection joint. For our analysis, samples for peel and shear test are also subjected to the temperature cycle test and characterized.

2 EXPERIMENTAL

2.1 Sample preparation

For all samples, commercially available multicrystalline 6” full square 3BB solar cells with an Al-BSF are used. The ribbon is a silver covered copper ribbon (1.5 mm x 0.2 mm). In case of the soldered reference for the thermal cycle test, the copper ribbon is covered with Sn62Pb36Ag2 solder and Kester 952s is used as flux. All ribbons are stretched by 0.5% prior to gluing. The curing conditions of the seven different ECAs are listed in Table 1. The laminates which were assigned to the temperature cycle test are build up with a glass and a layer of EVA at the front, followed by the cell matrix and a layer of EVA and a back sheet at the rear side. In case of the peel and shear test samples an additional layer of non-adhesive foil is added in order to remove them from the laminate after TC600.

Each ECA is cured according to the data sheet. The curing time and temperature is given in Table I.

Table I: Curing conditions of the ECAs used

ECA	temperature	curing time
A	160°C	3 min
B	180°C	0,5 min
C	180°C	10 min
D	180°C	5 min
E	180°C	10 min
F	180°C	10 min
G	180°C	10 min

The different sample designs are chosen depending on the characterization that is done and are shown in Figure 1. In case of the peel test samples, the ribbon is placed over the complete busbar. For each ECA, one cell is prepared. For the shear test, an ECA area with a length of about 10 mm and a width according to the busbar (1.5 mm) is made. For each ECA, six interconnection joints are made. The modules for IV measurement and electroluminescence characterization are made of a string with three interconnected cells. For each ECA, two electrically independent strings are made.

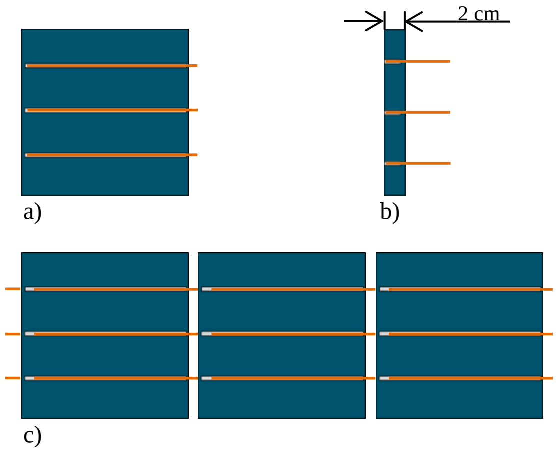


Figure 1: Schematic drawing of the samples. a) sample for peel tests, b) sample for shear test, c) sample for temperature cycle test

The curing of the ECAs and the soldering is done under reproducible conditions on a semi-automatic contact soldering station. The samples are subjected to the temperature cycle test following IEC 61215. The samples for the peel and shear test are used to analyze the forces for the initial state and after 600 temperature cycles.

2.2 Peel and shear test

In the PV industry the 90° peel test is an established method to characterize the mechanical properties of an interconnection joint. It is recommended to achieve a peel force of 1 N/mm joint width. A schematic drawing is shown in Figure 2. The sample is fixed on a substrate and the ribbon is pulled in a 90° angle.

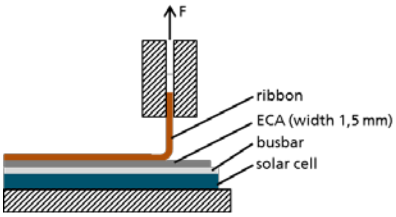


Figure 2: Schematic drawing of the 90° peel test

As the mechanical loading of cell and ribbon in laminated modules is expected to be dominated by shearing modes we introduce a 0° lap-shear test for the mechanical properties of the interconnection joint. Figure 3 shows a schematic drawing. The sample is fixed on a substrate and the ribbon is pulled in a 0° angle.

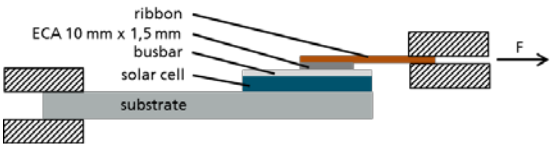


Figure 3: Schematic drawing of the shear test

3 RESULTS

3.1 Peel forces

Figure 4 shows the results for the peel test at initial state and after TC600. Only ECA D fulfills the criterion of 1 N/mm in the 90° peel-test at initial state.

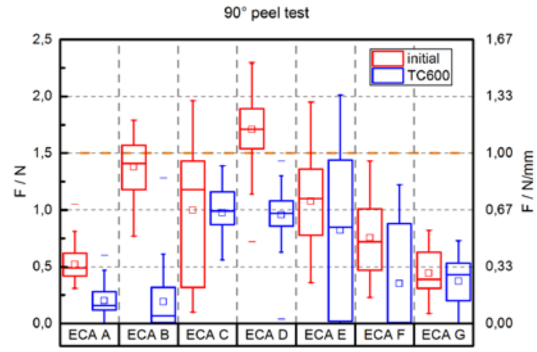


Figure 4: Results of the 90° peel forces in initial state and after TC600.

After the temperature cycle test, the measured peel forces drop for every ECA tested. In case of ECA E and ECA F the values show a wider spread. This is due to low peel forces at the edges of the interconnection joint and values in the middle that are at a comparable level of the initial state.

3.2 Shear forces

The result of the 0° shear test is shown in Figure 5. Besides ECA A, the results show a similar trend to the 90° peel test which is not necessarily expected because the different applied loading mode.

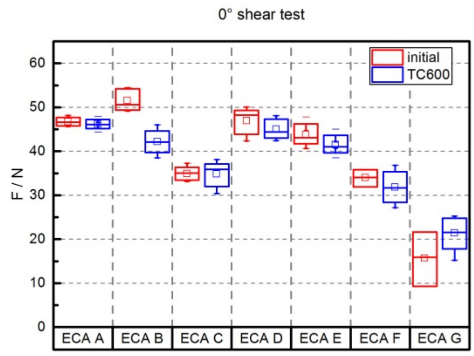


Figure 5: Results of the 0° shear forces in initial state and after TC600.

Besides ECA B, the measured shear forces after the temperature cycle test remain at their initial level.

A comparison of the measured adhesive force in case of the peel test and the shear test shows three adhesives which will be investigated in more detail: ECA A, which shows poor adhesive forces in terms of the peel test but performs well in terms of the shear test. ECA D, which performs well in both tests and ECA G, which shows the worst results of the ECAs tested.

3.3 IV measurement

The temperature cycle test according to IEC61215 is considered a highly relevant test for the reliability of interconnection joints as it addresses the thermomechanics of joints and module. Figure 6 shows the normalized results of the module efficiency. For each ECA, two independent cell strings are measured. All the samples pass 600 temperature cycles of the ongoing temperature cycle test. In this state, the measured adhesive forces in terms of the peel and shear test do not show an influence on the performance of the ECAs in a PV-module.

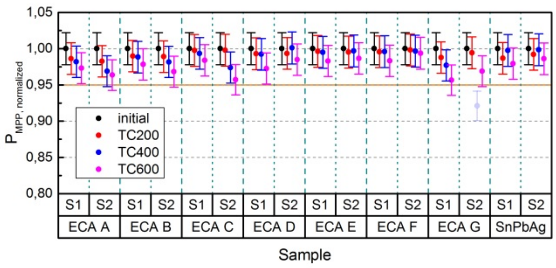


Figure 6: Normalized efficiency for each ECA and string. After one round of tempereture cycle test according to IEC61215, all samples have passed the test with less than 2% loss in efficiency. For each ECA and the soldered reference, two strings are tested (S1 and S2)

The IV-data show that the losses in efficiency result from FF-losses and are thus directly linked to the interconnection quality (Figure 7). The values for short circuit current and open circuit voltage remain stable.

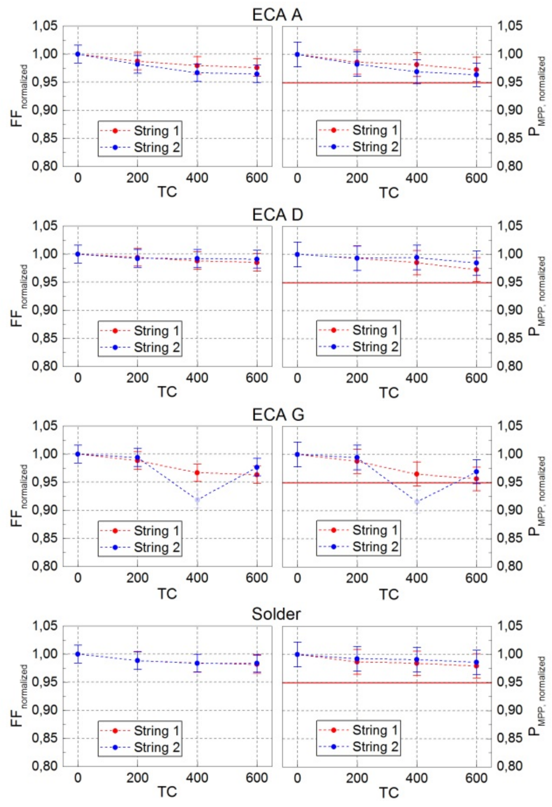
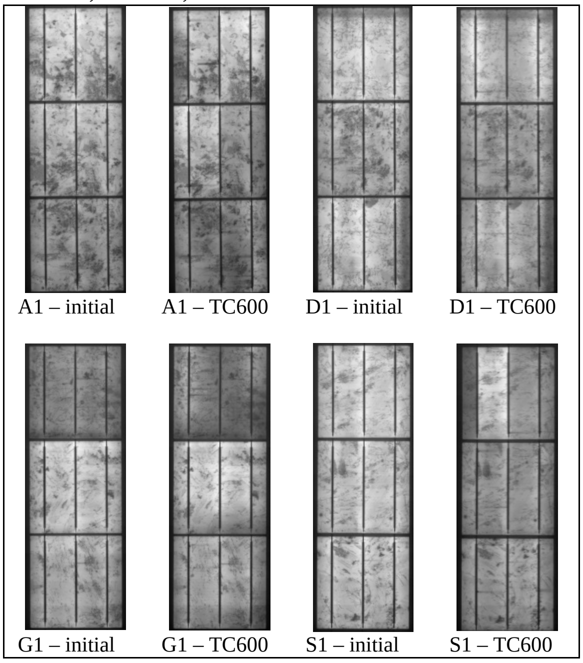


Figure 7: Normalized fill factor and power of three ECAs and the soldered reference.

3.4 Electroluminescence imaging

In addition to the IV-measurement, electroluminescence imaging is performed to get a better understanding of the occurred failure mode. Images are taken with 4 A forward bias current. After 600 temperature cycles only the module with ECA A shows suspicious areas.

Table II: Comparison of electroluminescence images of ECA A, D and G, as well as the soldered reference S.



4 SUMMARY

We present results of a comparison between a 90° peel test and a 0° shear tests of solar cells interconnected with seven different commercial available ECAs. Six of the seven ECAs in the test show a correlation between the measured initial peel and shear forces. The comparison of the electrical performance of 3-cell modules after the temperature cycle test according to IEC 61215 shows that all modules pass 200 temperature cycles with a power loss < 2% and 600 cycles (3x standard) with a power loss < 5%, although in the initial state only one ECA passes the 1 N/mm criterion in terms of the 90° peel test. The results clearly prove that adhesive forces below 1 N/mm for solar cells interconnected by conductive adhesives do not necessarily result in a failure in the temperature cycle test. In fact, we show that the glued joints withstand extended reliability testing.

5 ACKNOWLEDGEMENTS

This project was funded by the German Ministry for Economic Affairs and Energy within the research project “KleVer” under contract number 0325833B.

6 REFERENCES

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