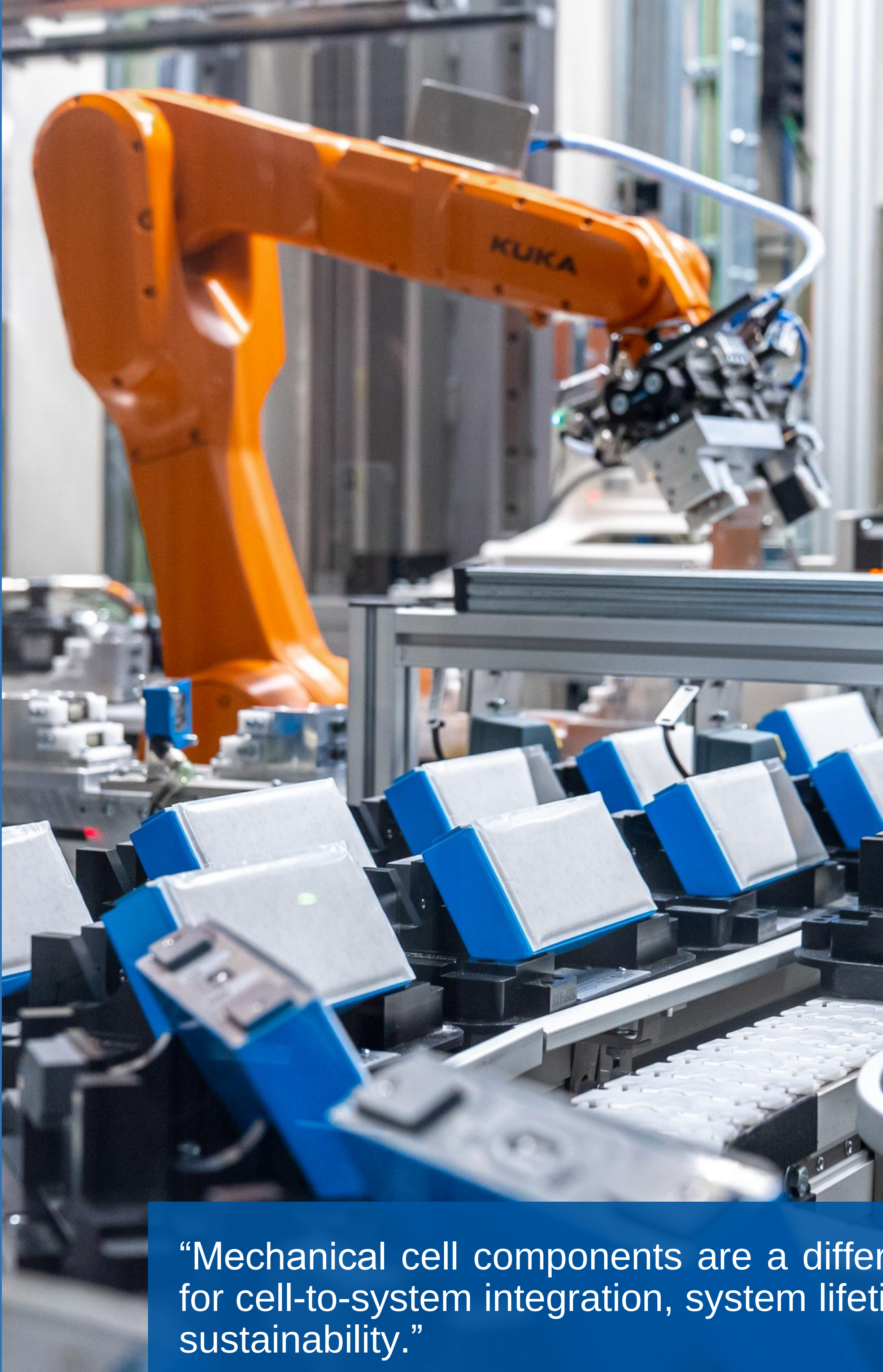
PET FILMS vs. UV COATINGS FOR LITHIUM-ION BATTERY CELLS

Surface Preparation of Lithium-Ion Battery Cells

Lankwitzer Premium Coatings

PEM | RWTH AACHEN UNIVERSITY



“Mechanical cell components are a differentiator for cell-to-system integration, system lifetime and sustainability.”

Prof. Achim Kampker,
PEM | RWTH Aachen University

EXECUTIVE SUMMARY

This white paper compares UV coatings and PET adhesive films as alternative exterior UV coatings for battery cells. To ensure validated and practical conclusions, two adhesive films and two UV coatings were subjected to various tests. The chosen UV coatings and films meet OEM standards and are currently used in the field by well-known OEMs. The purpose of the tests was to replicate the mechanical and electrical stresses encountered during operation and to ensure performance under extreme conditions. The test results demonstrate that the UV coatings outperformed the adhesive films in both mechanical and electrical tests, especially under end-of-life conditions. This indicates that UV coatings represent a promising alternative to the commonly used adhesive films, especially for battery systems designed for long-term durability in challenging environmental conditions.

CONTENT

INTRODUCTION

INSULATION OF BATTERY CELLS

The adoption rate of battery electric vehicles (BEVs) classifies as one of the quickest expanding areas in the automotive sector. According to a recent McKinsey forecast, more than 200 battery cell factories will be constructed by 2030 to meet increasing demand. The market for cell components is projected to expand at an annual rate of 19% through 2030, ultimately surpassing €232 billion.[1] Looking at insulation material for prismatic batteries alone, the material volume is projected to grow by a factor of 6 in Europe until 2030 (see Fig. 1).

Adhesive PET films have become the insulation material of choice for prismatic battery cells in the Asian market due to their ease of manual processing, low component costs, and high availability. In contrast, UV coatings offer high flexibility in terms of thickness and adaptability to the complex geometries of battery cells. UV coatings provide precise and uniform coverage of the battery cells, leading to effective insulation and protection from external influences. Also, UV coatings are highly automatable, exhibit low production rejection rates, and promise to offer improved adhesion and resistance to chemical substances, enhancing durability over the lifespan of a battery system. The trends of cell-to-pack or even cell-to-chassis integration strategies, as well as high-energy cells with significant expansion during cycling and over their lifetime, lead to increased requirements for the performance and flexibility of mechanical insulation materials throughout the cells' lifetime.

The aim of this study is to compare the advantages and disadvantages of UV coatings and adhesive PET films. Therefore, experiments are conducted to test the key functional requirements of mechanical durability and permanent electrical insulation.

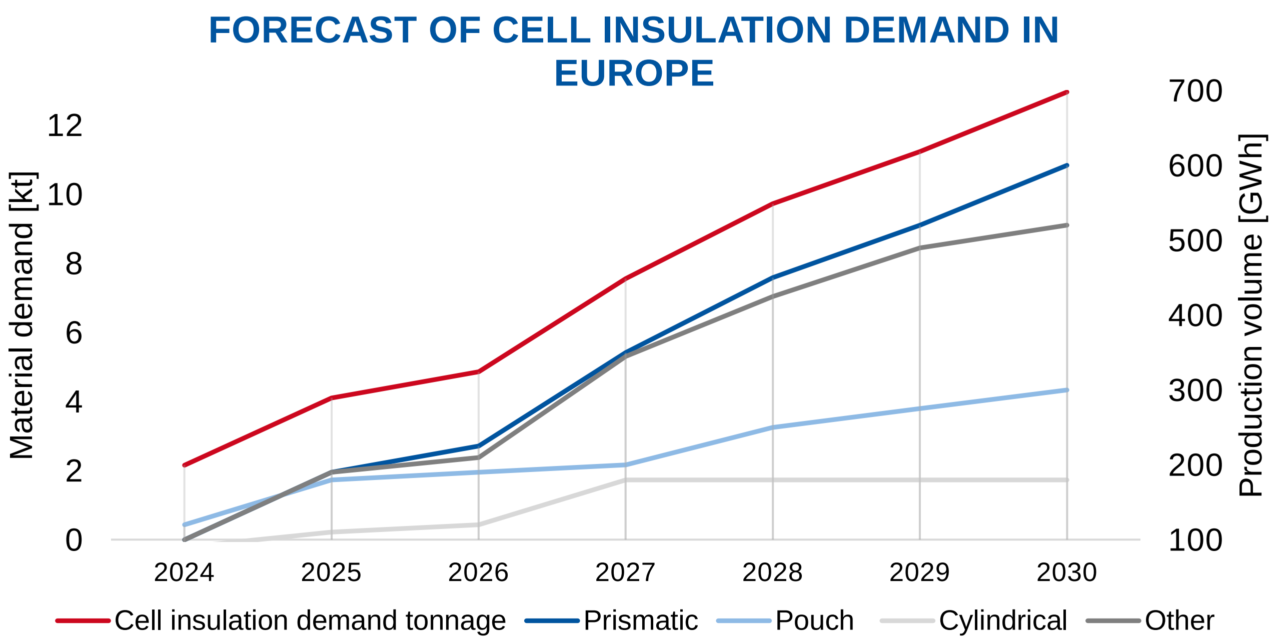


Figure 1: Forecast of annual battery cell production volumes in gigawatt-hours (GWh) and insulation material demand for prismatic battery cells in kilotons (kt)[2]

UV – Ultraviolet   PET – Polyethylenterephthalat

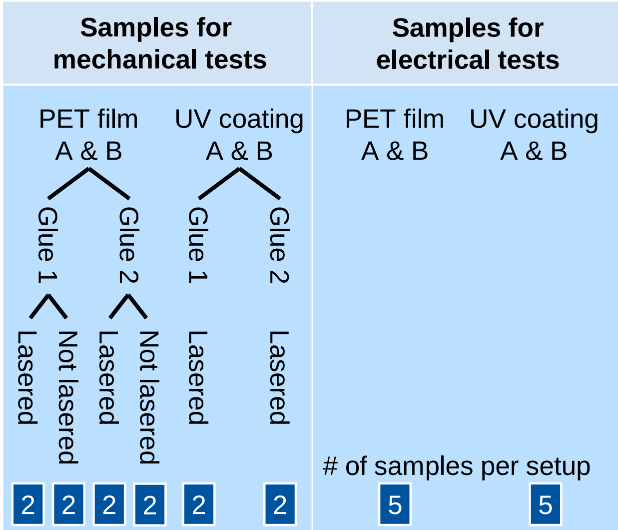
EXPERIMENTAL SET-UP

GENERAL APPROACH

To assess the suitability of the insulating materials for the application on prismatic battery cells for automotive battery systems, they are subjected to mechanical and electrical tests. The goal of these tests is to evaluate the performance at the begin of life (BOL) as well as at the end of life (EOL). Two aging tests – condensation and climate cycling – are chosen to simulate the aging behavior of the test samples in an expedited manner. Two different films that are currently being used by OEMs to insulate the prismatic battery cells in their electric vehicles (PET films A & B) and two different UV coatings which are also currently applied by major OEMs (UV coatings A & B) are compared to each other. The thickness of the films and the UV coatings lies in a similar and typical range of ~0.1 millimeters (see Fig. 2).

Each mechanical test is conducted with two samples per setup, while each electrical test is conducted with five samples per setup (see Fig. 2). The samples for the electrical tests are 120 x 300 x 2 mm aluminum plates (Al3003), whereas the samples for the mechanical tests are two 100 x 25 x 2 mm plates (Al 3003). The coating is directly applied on the aluminum after laser pre-treatment and cured using UV-curing technology. The films are attached using their respective film specific adhesive with and without laser pre-treatment (see Fig. 2 & 5).

TESTING SAMPLES



Type	Thickness [μm]
PET film A	76 - 102
PET film B	90
UV coating A	105 - 124
UV coating B	88 - 98
Glue 1	1,000
Glue 2	300

TESTING MATRIX

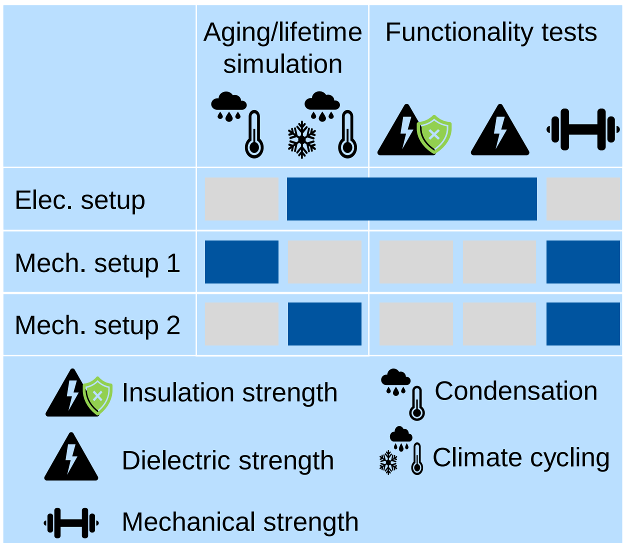


Figure 2: Sample and testing procedure overview

BOL – Begin of Life EOL – End of Life

AGING TESTS

The aging tests aim to simulate the behavior of insulation materials at the end of life. Heat and humidity are used to induce accelerated aging conditions.

The condensation test is based on DIN EN ISO 6270-2 and thus complies with industry standards. In this test, the sample is exposed to a temperature of 40°C for 240 hours, with humidity maintained constantly at 100% (see Fig. 3).[3]

The climate cycling test also subjects the sample to heat and humidity stress. However, in this test, the sample undergoes 20 cycles. Each cycle has a duration of twelve hours, resulting in a cumulative testing time of 240 hours. During each cycle, the temperature varies between -30°C and 60°C, whereas humidity varies between 20% and 80% (see Fig. 3).

ELECTRICAL TESTS

Two different electrical tests are conducted: the measurement of insulation resistance and the measurement of dielectric strength. It is ensured that the same spot on the test sample is used for the measurements before and after the aging tests.

The measurement of insulation resistance is performed according to the setup shown in Figure 4. The test sample is connected to a power source using two electrodes. The insulation resistance is then measured at 2.7 kV.

The measurement of dielectric strength is carried out with a similar setup: The test sample is connected using two electrodes. In this test, the dielectric strength is measured at 2.7 kV and 3.4 kV by applying and holding the voltage while ensuring no electrical breakdown occurs (see Fig.4).

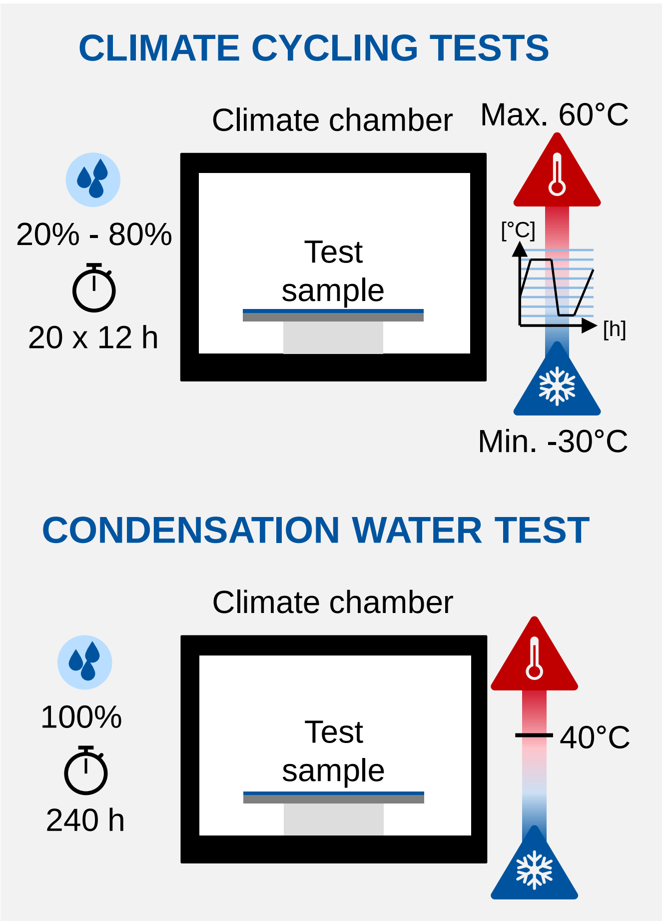


Figure 3: Aging tests

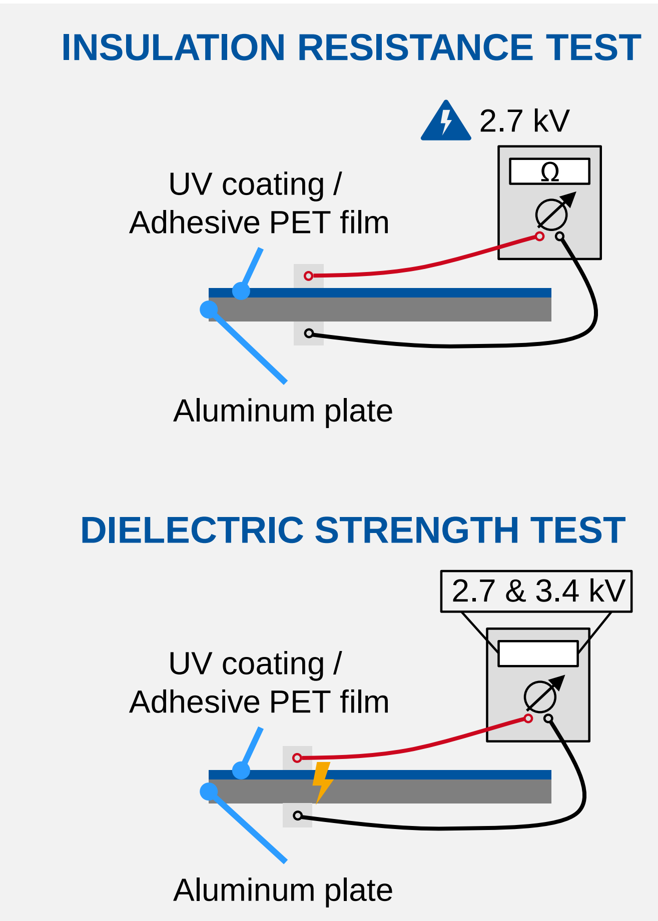


Figure 4: Electrical test set-up

MECHANICAL TESTS

In the mechanical tests, the setup differs from the electrical tests. The basic setup of the test samples has already been explained in Figure 5. Both types of test samples are bonded together using two different glues (Glue 1 and Glue 2). This adhesive joint is labeled as “glue joint 1” in Figure 5. The two glues differ not only in strength but also in thickness. Glue 1 is one millimeter and Glue 2 is 0.3 millimeters thick. Two test samples are bonded in an over-lapping area (overlap length of 12.5 mm) using the respective glue and plasma cleaning.

After the test samples are bonded, both ends are subjected to tensile loading. This creates a shear load on the composite layer of coating and adhesive, or film and adhesive. The force applied to the load is progressively increased. The test continues until the composite layer fails. When this failure occurs, the fracture point is analyzed, and the maximum failure force before non-elastic deformation is recorded. The recorded force is then converted to mechanical stress.[4]

LAP SHEAR STRENGTH TEST – UV COATING

LAP SHEAR STRENGTH TEST – ADHESIVE PET FILMS

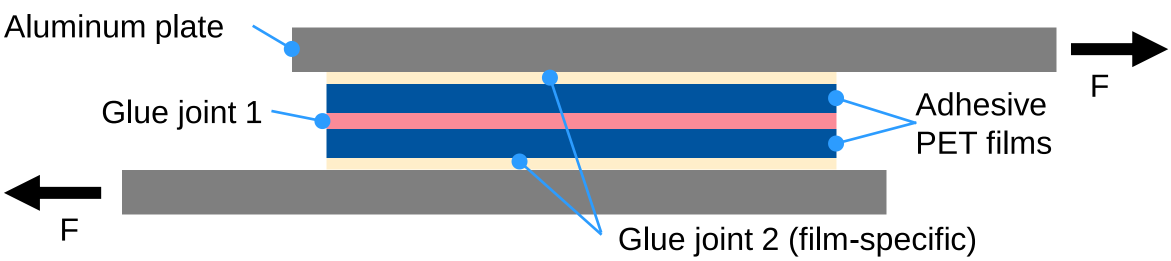


Figure 5: Setup of the mechanical test

EXPERIMENTAL RESULTS

ELECTRICAL TEST RESULTS

The electrical tests were conducted both before and after the aging test for both types of coatings, using the climate cycling test as the aging method. Comparing the insulation resistances of the PET films with those of the UV coatings reveals that the UV coatings exhibit higher values, especially at the beginning of life. UV coating A shows a value almost four times higher than the films. At the end-of-life results, it can be observed that the films do not lose as much electrical insulation performance as the UV coatings.

In contrast, the aging process significantly affects the coatings, with their values almost halving.

Nevertheless, the insulation resistance of UV coating A still exceeds that of the films, even surpassing the beginning-of-life results. UV coating B performs slightly worse than film A and at the same level as film B (see Fig. 6).

The results of the dielectric strength tests were positive for all tested variants, as no electrical breakdown occurred at 2.7 kV and 3.4 kV.

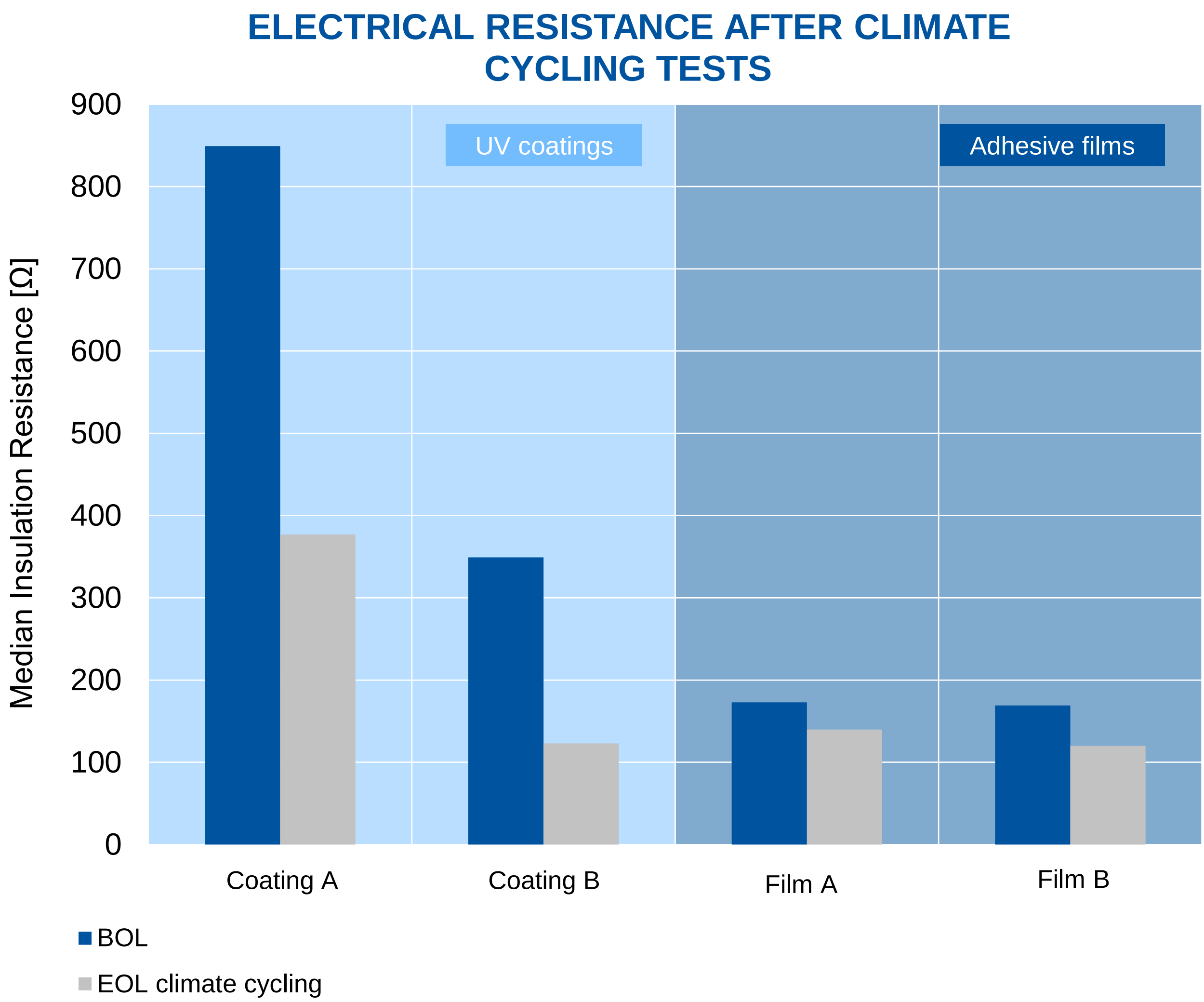


Figure 6: Insulation resistance before (BOL) and after (EOL) aging in climate cycling test conditions

The results show that the aging tests have a negative impact on the insulation properties of the films and UV coatings. This is presumably caused by charge carriers in the form of water that might have diffused into the coatings. Another possibility is that the homogeneous structure of the coatings might have broken down, making them more permeable. One explanation for the lower insulation degradation of the films could be the additional (film-specific) adhesive layer breaking down and decreasing the interface to the aluminum, thereby counteracting the aforementioned effects. Determining the exact cause would be the subject of further investigation.

MECHANICAL TEST RESULTS

The test results represent the maximum stress at which the test samples failed under load (see Fig. 7). Upon reviewing the results, it is noticeable that the UV coatings withstood higher stress and therefore exhibited more than twice the strength of the films. This holds true for both the BOL and EOL assessments.

A noteworthy observation with the UV coatings is that the test samples using Glue 2 showed increased strength after the condensation test. When examining the films, differences in the test samples' behavior can be observed depending on the glue used

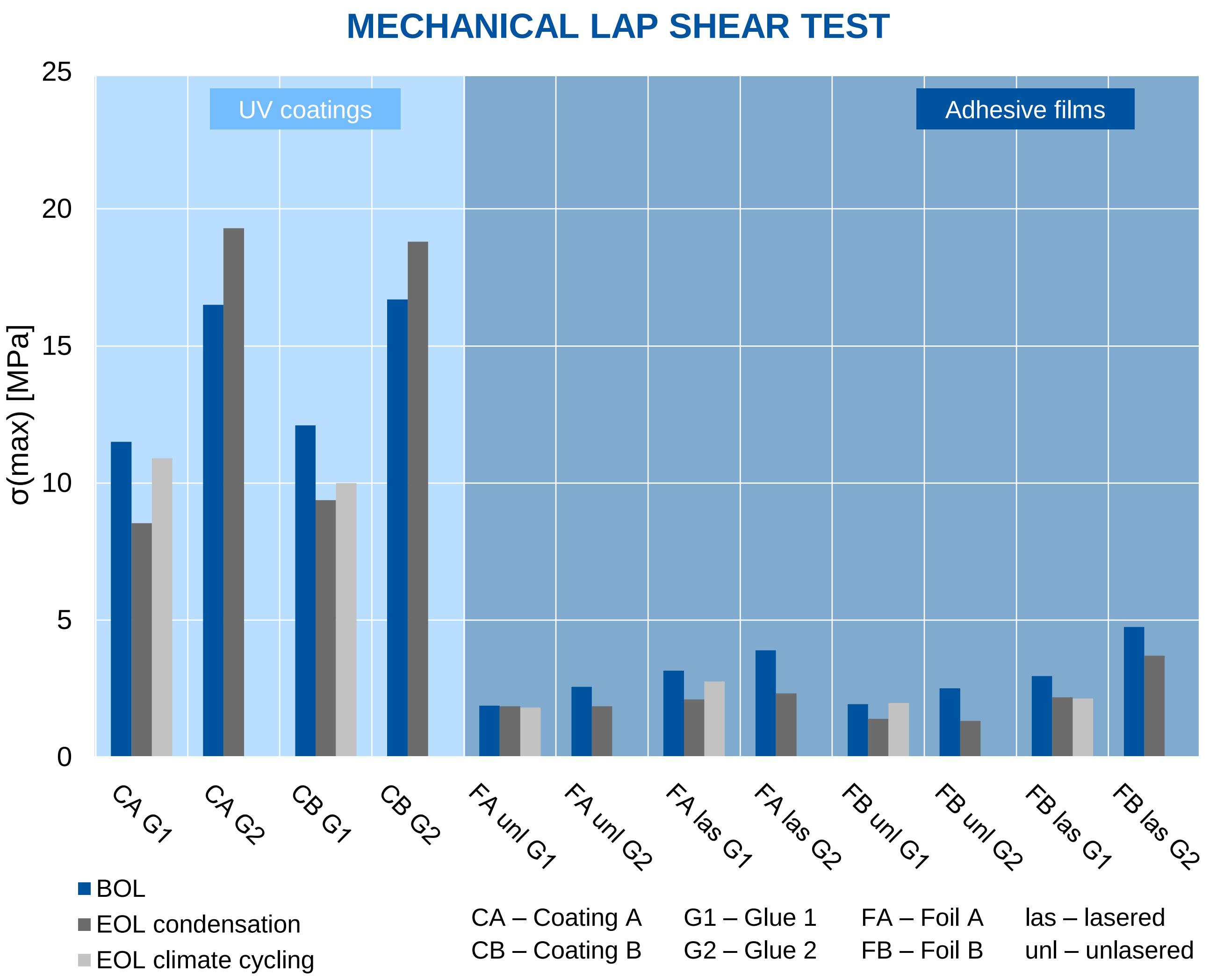


Figure 7: Lap shear test results before (BOL) and after (EOL) aging

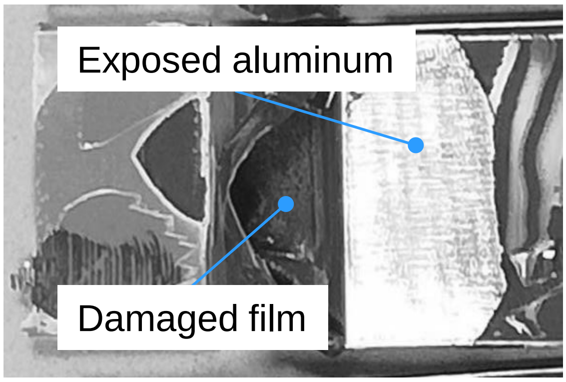
and the surface treatment applied. If a surface was treated with a laser, the strength increased at both BOL and EOL compared to the untreated surface. This effect was observed for the films with both glues at BOL and EOL. The best performance of film test samples was observed in the test samples with a laser-treated surface and Glue 2. Both films behaved very similarly regarding aging behavior and failure stress levels at both BOL and EOL.

The aging tests had a more moderate impact on the films than on the UV coatings when comparing the samples using Glue 1. UV coatings with Glue 2 showed higher strength after the condensation test, while film samples with Glue 2 showed similar failure strength degradation as film samples with Glue 1.

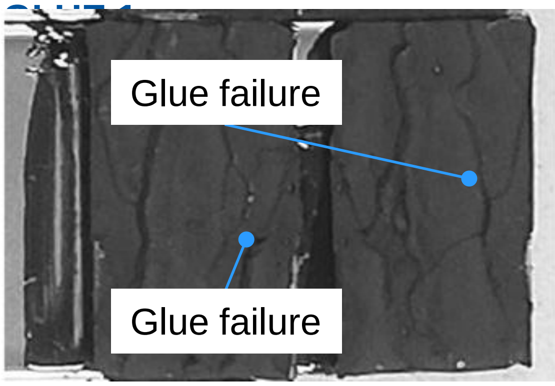
For the films, all failures included some form of debonding from the aluminum for both BOL and EOL results with Glue 1 & 2. Regarding the UV coatings, Glue 1 always failed by failure of the glue itself at BOL and EOL, while Glue 2 always caused the UV coating to detach from the aluminum at BOL and EOL. Figure 8 shows all the respective debonding modes.

Looking at the failure modes and failure stresses, it can be summarized that the aging of the UV coatings seems to increase the adhesion of the coatings to the aluminum, making glue selection vital for optimum lifetime stability. In parallel, the adhesion of the films is primarily determined by the film-specific adhesive used, which also accounts for its degradation of failure stress levels after aging. Glue thickness might also play a role in the maximum strength determining failure mode.

PET FILM – ALUMINIUM DEBONDING – REPRESENTATIVE FOR ALL FAILURE MODES



UV COATING – GLUE DE-BONDING – REPRESENTA-TIVE FOR ALL FAILURE MODES WITH GLUE 1



UV COATING – ALUMINIUM DEBONDING – REPRESENTATIVE FOR ALL FAILURE MODES WITH GLUE 2

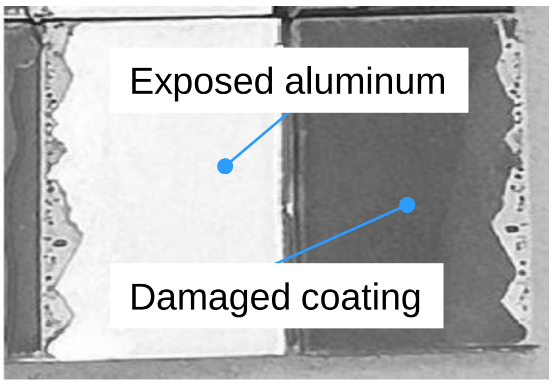


Figure 8: Representative failure modes of the test samples

RESULT SUMMARY AND INTERPRETATION

UV COATINGS VS. PET ADHESIVE FILMS

In summary, the UV coatings outperform the PET film in their core functions to insulate and to provide sufficient mechanical integrity throughout the battery system's lifetime (see Fig. 9). While the electrical insulation performance of the films is comparable to or within a similar range as the UV coatings, the mechanical strength and lifetime stability of the UV coatings are twice as good in terms of shear force resistivity. Regarding electrical insulation stability throughout the lifetime, the UV coating insulation degradation was slightly more pronounced than film insulation degradation. Coating A and film A slightly outperformed their respective counterparts regarding electrical insulation. The results in section 3 also showed the importance of glue selection and surface preparation. The glue has a significant influence on the aging behavior of the UV coatings' mechanical joints. For the films, the adhesive used to attach the film to the cell was the key factor in mechanical failure at the beginning of life and after the aging tests. The surface treatment of the aluminum via lasering increased PET film integrity throughout its lifetime but could not enhance it to achieve mechanical performance comparable to the UV coatings.

These results can support selecting the appropriate cell insulation approach for a specific application. For high requirements regarding mechanical joining, flexibility of the insulation geometry for cell breathing and expansion, as well as lifetime integrity, UV coatings show a significant improvement over the currently often applied PET films.

	Mechanical performance		Electrical performance	
Cell insulation material	**BOL**	**EOL**	**BOL**	**EOL**
UV coating A	●	●	●	●
UV coating B	●	●	◕	◑
PET film A	◑	◔	◑	◑
PET film B	◑	◔	◑	◔

● Best result ◕ Next to best ◑ Next to worst ◔ Worst result

Figure 9: Qualitative summary of the test results

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The Chair of **Production Engineering of E-Mobility Components (PEM) of RWTH Aachen University** was founded in 2014 by Professor Achim Kampker and is active in the field of lithium-ion battery production technology for many years. PEM covers all aspects of the development, production, and recycling of battery cells and systems. Due to a large number of industrial projects with companies of all stages along the value chain and due to central positions in renowned research projects, PEM offers extensive expertise.

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