



Master thesis

Master's Program in Mechanical
Engineering, 60 credits

Quantitative measurements and
influence assessment on chemical
surface cleanliness

Mechanical engineering, 15 credits

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Preface

This thesis marks the culmination of our master's program at Halmstad University, representing months of research, experimentation, and collaboration. We extend our sincere gratitude to the individuals who supported us throughout this journey:

First, we thank Sabina Rebeggiani, our academic supervisor at Halmstad University, for her guidance. Her expertise was invaluable whenever we encountered challenges or needed clarity in our research direction.

We are deeply grateful to our industrial supervisors at Scania, Gabriella Rendén and Alexey Kuznetsov. Their insights into Scania's manufacturing challenges and their willingness to share company-specific knowledge were instrumental in shaping this project's relevance.

We also wish to thank Zygo Ametek and TechTest RecognOil for providing access to critical instruments and software. Zygo supported the project by supplying their film thickness measurement software for interferometry analysis, and TechTest provided the RecognOil 3W fluorescence system, which played a key role in our contamination evaluation.

Finally, we thank Aron Chibba for providing us with the opportunity to carry out this thesis and contribute to ongoing research in surface contamination and adhesion.

This collaboration between academia and industry has been both enlightening and rewarding, and we hope our findings will serve as a foundation for future work in this field.

Abstract

This thesis investigates the relationship between chemical surface contamination and adhesion performance in industrial applications, focusing on insulation tape used in Scania's battery module production. Two manufacturing challenges are addressed: poor laser weld quality and tape adhesion failures, both stemming from surface contamination by oils and greases.

Due to equipment limitations and time constraints, the study prioritizes the development of methods for contamination measurement and evaluating the effects on tape adhesion. Interferometry, fluorescence spectroscopy, and gravimetric analysis were applied to quantify surface cleanliness, and a custom-built tape peel test rig was used to simulate real-world adhesion performance.

Experiments demonstrated a measurable correlation between increased surface contamination and reduced adhesion force. Fluorescence measurements proved effective in detecting relative contamination levels, though accurate quantification depended on substrate type and oil properties. A strong link between fluorescence intensity and adhesion strength was observed for uncoated steel plates, highlighting the technique's potential for quality control applications.

The results support Scania's need to define contamination thresholds and establish process reliability, even when the exact contaminant is unknown.

Keywords: surface contamination, fluorescence spectroscopy, tape adhesion, thin film measurement, manufacturing quality

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List of Abbreviations

Abbreviation	Explanation
ASTM	American Society for Testing and Materials
CAD	Computer Aided Design
FTIR	Fourier Transform Infrared Spectroscopy
ISO	International Organization for Standardization
PIB	Polyisobutylene, a synthetic rubber used in adhesives, sealants, and coatings
SCC Grade	A negative logarithmic value representing the maximum allowable chemical concentration on a surface, expressed in grams per square meter (g/m ²).
UV	Ultraviolet
XPS	X-ray Photoelectron Spectroscopy

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1 Introduction

This chapter introduces the context and motivation behind the thesis. It begins with a description of Scania as the industrial partner and outlines the contamination challenges faced in their battery production. The specific problems involving welding defects and tape adhesion failure are then presented, followed by the overall problem definition and research objectives. Finally, the chapter addresses the key limitations encountered during the project and describes the study environment in which the work was carried out.

1.1 Introduction of Client

Scania is a leading global manufacturer of trucks, buses, and engines, as well as a provider of sustainable transport solutions. Founded in 1891 and headquartered in Södertälje, Sweden, Scania has built a strong reputation for innovation, reliability, and efficiency in the commercial vehicle industry. The company operates as part of TRATON GROUP, a subsidiary of Volkswagen AG, which further strengthens its global presence and technological capabilities.

For this thesis, Scania serves as an industrial partner investigating quantitative measurements for chemical surface cleanliness to assess contamination effects in manufacturing. The research aims to enhance Scania's production quality by developing reliable methods to detect and mitigate surface contaminants, ultimately improving component longevity and reducing waste. This collaboration provides access to real-world industrial challenges and data, bridging academic research with practical applications in advanced manufacturing.

1.2 Problem Background

In Scania's assembly of batteries for electric trucks and buses, chemical surface contamination has emerged as a critical challenge affecting manufacturing quality. Two key issues were identified:

Busbar Welding Defects: Battery cells are interconnected via busbars, which are laser-welded for conductivity. Contamination (e.g., oils or grease) on busbars from suppliers led to poor weld quality, compromising electrical performance and structural integrity.

Insulation Tape Adhesion Failure: Certain battery frame plates require insulation tapes for safety, but chemical contaminants on these surfaces caused adhesion failures, risking electrical hazards.

1.3 Problem Definition

This thesis aims to research and assess methods to quantitatively measure chemical contamination (oil/grease thickness) on coated plates used in battery frames, building upon prior research e.g., (Namousi, 2024).

In parallel, it investigates the impact of such contamination on the adhesion performance of insulation tapes by establishing reproducible testing protocols. Based on these findings, the thesis seeks to propose actionable standards or contamination thresholds that ensure reliable tape adhesion within Scania's battery production process.

1.4 Limitations

The most significant limitation throughout this project was time. Several delays in equipment availability reduced the overall testing window considerably. The interferometry system could not be used for film thickness measurements for an extended period due to a damaged cable, and it took considerable time before a replacement arrived. Additionally, the fluorescence spectroscopy device—intended as an alternative contamination quantification method—also arrived late in the project, leaving only a few weeks to perform all related measurements.

Another limitation was the inability to test laser welds, which restricted the scope of the experimental work. As a result, the focus shifted almost entirely to tape peel testing as a practical and accessible method for evaluating surface contamination effects.

Although a dedicated tape peel tester was not available, a custom test setup was built using available equipment. While not ideal, it delivered results with acceptable accuracy for comparative analysis. However, the contamination methods used in the study were relatively basic and lacked precision, resulting in limited reproducibility between tests.

Lastly, further testing with a tensiometer was initially planned to complement the other methods, but the machine was found to be non-functional during the project period, and no replacement was available.

1.5 Individual responsibility and efforts during the project

The project was carried out collaboratively, with responsibilities divided.

Christoph Foltin was primarily responsible for the literature review concerning the influence of contamination on weld quality, as well as all work related to surface cleanliness measurement techniques. This included the development and execution of procedures involving the interferometer, fluorescence spectroscopy, and gravimetric analysis, along with cleaning and contamination protocols. Christoph also handled the data processing and correlation of measurement results, and analyzing and discussing findings related to contamination quantification.

Arne Reynaert focused on the literature review concerning the effects of contamination on tape and adhesive performance and was responsible for all aspects of the tape adhesion testing. This involved the design and execution of cleaning, contaminating, and testing procedures, as well as data handling and analysis related to adhesion performance. Arne also designed and built the tape testing setup and custom 90° peel test jig, which enabled repeatable adhesion testing.

While tasks were divided to ensure depth and focus in each area, the overall project was shaped through continuous collaboration, joint decision-making, and shared writing responsibilities.

1.6 Study Environment

This thesis work was conducted at Halmstad University, where three key facilities for different phases of the project were utilized. The majority of experimentation time was spent in the Microscopy Lab, conducting surface analysis and contamination measurements. The actual tape adhesion tests were performed in the Research Lab, while sample preparation and test setup construction took place in the FabLab workshop.

Throughout the project, the collaboration with Scania engineers provided technical guidance and test materials to ensure testing methods remained relevant to their manufacturing processes.

2 Methods

This chapter outlines the methodology used to investigate surface contamination and its effect on tape adhesion in battery assembly applications. It begins with a literature review to identify relevant measurement techniques and previous research. The following sections describe the cleaning procedures, measurement techniques, contamination application methods, and testing protocols developed for the study. All methods were selected or adapted based on the available equipment, with the aim of producing reliable and repeatable results under realistic laboratory constraints.

2.1 Literature Research

In order to get a good understanding of quantitative chemical surface cleanliness measurements, a systematic literature review was carried out. This first face of the thesis was aimed at identifying validated methods, industry standards, and contamination thresholds relevant to Scania's battery assembly challenges. The way this literature research was carried out is partly based on the methodology of (Snyder, 2019).

2.1.1 Data collection

The literature research was conducted across several academic databases, including: Google Scholar, ScienceDirect, ResearchGate, SpringerLink, and Scopus. These platforms were selected for their extensive coverage of engineering, materials science, and manufacturing research.

The key search terms used included combinations of chemical cleanliness, organic contamination, surface cleanliness measurement, oil film thickness, adhesion failure mechanisms, ISO cleanliness standards, and thin film analysis.

2.1.2 Literature Review Method

Due to the limited number of studies directly addressing contamination-related challenges in manufacturing, and the fact that two distinct problems—laser weld quality and tape adhesion—stem from the same root cause, the research was divided into two parts: the effects of surface contaminants on laser welding, and their effects on tape adhesion. To guide the literature review, a set of inclusion criteria was defined. The focus was specifically on oils and greases as contaminants, while studies involving particulates or oxides were not included. From each selected study, key information was extracted, including the methods used for contaminant application and measurement, as well as any reported thresholds for welding or adhesion failure, where available.

2.2 Cleaning

The cleaning procedure was adapted from (Doraciak, Bunting and Lampke, 2019), which described an extensive multi-step cleaning process. While the original method uses ultrasonic baths and specialized solvents, practical constraints forced a simplified method. Due to the size of the plates, they were incompatible with the available ultrasonic bath. Therefore the cleaning method was reduced and changed to the available tools.

1. **Solvent Rinsing:** high-purity ethanol ($\geq 99.7\%$) to dissolve and remove contaminants
2. **Mechanical Wiping:** Wiping the test surfaces multiple times with a paper towel to remove dissolved contaminants, repeat step 1-2 three times
3. **Solvent Rinsing again:** flushing with ethanol to remove contaminants and fibers from the paper towel

2.3 Measuring

After both cleaning and intentional contamination, the cleanliness of the specimen must be assessed to determine the extent of contamination.

Various methods are available for evaluating the state of the specimen. This section outlines the techniques selected for this purpose. All possible methods are described in 3.2 Measurement Techniques. The choice of methods was based primarily on the equipment and facilities available at the university, with preference given to those most likely to provide quantifiable results.

2.3.1 Interferometric Surface and Film Thickness Measurement

To evaluate the presence of thin contaminant films, a white-light interferometric technique was employed. The Zygo NewView 9000 interferometer, a non-contact optical profiler based on white-light interferometry, was used for all measurements. This method is particularly suited for detecting changes in micro-roughness and film thickness due to its high vertical resolution of 0.08nm and ability to differentiate optical interfaces in transparent films.(Zygo, 2025b)

The interferometer works by emitting broadband white light toward the specimen surface and detecting the interference pattern created by reflected light. The phase shift between the reference and reflected beams is analyzed to generate a height map. When thin films are present, the device captures reflections from both the film's top surface and the underlying substrate. If the film is sufficiently thick and transparent, the phase difference between these two reflected signals allows for the calculation of film thickness. This approach enables simultaneous acquisition of surface roughness and film thickness data, limited by the optical resolution of the system. For the Zygo NewView the lower limit for film-thickness measurements is 1.5 μm .(Zygo, 2025a)

Measurement parameters were carefully adjusted depending on the specimen state. Clean samples typically exhibited a more uniform surface and were measured with a scan depth of 20 μm . Contaminated specimens, which often displayed uneven film coverage and surface deformation, required greater scan depths of 40 μm or 65 μm , depending on the degree of surface roughness.

For each specimen condition (cleaned or contaminated), a total of 25 measurements were taken in a fixed 5×5 grid pattern. The specimens were physically marked to ensure repeatability of the measurement pattern across different surface states and test iterations. Each measurement generated four output layers: Top Surface, Secondary Surface, Thickness, and Intensity. All layers were exported and saved in a unified data file format for post-processing. For film measurements, the software allows adjustment of critical parameters including the Threshold (signal detection sensitivity) and Refractive Index (used for interpreting film optical properties). Threshold values were experimentally optimized and set to 7 % for Tests 1–3, and 5 % for Tests 4–5. The refractive index, which influences the calculated film thickness, was set to 1.4—an approximate value for machine oils. As the exact refractive index of the contaminants was unknown, this value was held constant across all measurements; however, no significant variation in results was observed due to this parameter.

2.3.2 Fluorescence Spectroscopy

The second measurement technique employed was fluorescence spectroscopy. Like the interferometric method, it is a light-based measurement technique. In an enclosed space, ultraviolet (UV) light is emitted and either absorbed or reflected by the specimen, depending on the materials present in the measurement area. When the UV light is absorbed, it temporarily elevates the energy levels of the electrons in the molecules (typically for $1\text{--}10 \times 10^{-9}$ seconds). As the electrons return to their original energy state, the excess energy is emitted as light. This emitted light has a longer wavelength than the UV light, which allows sensors to detect it and measure its intensity. (Molecular Probes, 2025)

Measurements obtained using this technique are relative to a reference sample and are therefore qualitative in nature.

The handheld device Reconoil 3W by TechTest was used for fluorescence measurements. The device covers an area of 27×20 cm and generates a detailed heatmap of the scanned surface. The measurement data were uploaded to the TechTest cloud platform for processing, which yielded mean fluorescence values for each measurement. To guarantee the accuracy of the measurements the device was calibrated by TechTest. (TechTest, 2025)

2.3.3 Gravimetric Analysis

Weighing the specimens and dilutions was carried out using the Sartorius BP211D microbalance. All measurements were performed in an enclosed chamber to minimize external influences such as air currents or temperature fluctuations. The scale offers a resolution of 0.01 mg for weights up to 80 g, and 0.1 mg for weights up to 210 g. (Fotosatz, 2000)

2.4 Application of Contamination

Several standardized techniques for controlled contaminant application were identified in the literature, including spin coating (Rehg and Higgins, 1992), dip coating (Griffin and O’Kane, 2018), and spray coating using diluted contaminant solutions. However, these methods were not feasible within the constraints of the available laboratory equipment.

As a result, a manual application protocol was developed for this study. For each test plate, a contamination area measuring 100×53 mm (or 100×100 mm) was marked. A predefined volume of contaminant was then applied to the center of this area using an adjustable-volume micropipette (Finnpipette F1, accuracy ± 0.1 μL). The liquid was subsequently spread across the marked region using folded paper wipes (25×25 mm, folded twice to form four layers), aiming for a uniform distribution.

While this approach allowed for practical execution of the tests, it introduced certain limitations. Specifically, variations in absorbency among the paper wipes led to minor inconsistencies in contaminant distribution. To mitigate this issue, each contaminated surface was inspected prior to tape application to verify the actual contamination level and ensure consistency across test conditions.

To overcome the absorption issue, a different method was used – dilution. When mixing a defined oil volume with a defined ethanol volume, a mixture is created. If the mixture is poured over the specimen and given ~ 10 min to let the ethanol evaporate, only the oil remains. That method enables calculating the thickness of the remaining oil by weighing the poured mixture and factoring in the mixture ratio.

2.5 Contamination Measurements

This section provides a comprehensive overview of all measurement techniques, tools, procedures. The aim is to evaluate the chemical cleanliness of surfaces before and after contamination or cleaning processes. Each measurement method was selected based on its ability to provide relevant and quantifiable data regarding surface condition, contaminant presence, or film thickness.

2.5.1 Tools

A variety of tools, both hardware and software, were utilized throughout the experiments to perform measurements, prepare specimens, and analyze data.

Hardware Tools:

The hardware included both measurement instruments and tools used for specimen cleaning and contamination.

- A Zygo NewView 9000, a white-light interferometer, was employed to measure film thickness on clean and contaminated specimens.
- A TechTest Recognoil 3W handheld device was used to measure the surface fluorescence of the specimens.
- Ethanol served as the primary cleaning agent and was also used for diluting oil in Experiment 3.

- Paper towels were used during the cleaning process and, when cut into smaller pieces, were also used to distribute contaminants uniformly across the surface.
- A Finnpiquette was used to dispense oils accurately onto the specimen surfaces.

Three different types of specimens were used:

- Standard steel plates (dimensions: 53 × 315 mm),
- Polished steel samples (100 × 100 mm),
- Coated steel plates provided by Scania.

Software Tools:

To analyze interferometric data, the following software tools were used:

- MX Software: Interprets raw measurement data from the Zygo interferometer and enables data export.
- MountainsLab 10: Processes the raw data into specific quantitative outputs such as detection rates and film thickness values.
- Microsoft Excel: Used for further post-processing, visualization, and statistical analysis of the processed data.

Fluorescence measurement data were directly uploaded and analyzed via the TechTest Cloud platform. The processed results were subsequently exported and further analyzed in Microsoft Excel.

2.5.2 Procedure

The following section outlines all procedures used throughout the experiments. Documenting the methodology in detail is essential in research, as it provides a structured plan of action, identifies potential variables, and ensures the repeatability and reproducibility of the results. Each step of the experimental workflow – ranging from specimen preparation to data acquisition – is described to enable consistent application in future studies or replications.

Experiment 1

The first experiment is designed to establish a correlation between the quantitative measurements obtained from the interferometer and the qualitative fluorescence measurements. The objective is to provide a meaningful numerical reference for the fluorescence-based results by linking them to quantifiable film thickness data. By generating a large dataset that includes both clean and contaminated surface states, and by evaluating the same specimen with both techniques, it was expected that the results would exhibit comparable trends and reinforce each other's findings.

For this experiment, the polished steel sample was chosen due to its manageable size and uniform surface condition. The procedure followed a three-step cycle, repeated across several iterations. Measurements were taken after each step to track surface changes:

1. Initial Cleaning
 - a. Measurement
2. Contamination
 - a. Measurement
3. Cleaning with Paper Towel
 - a. Measurement

Six locations were analyzed using the Reconoil 3W fluorescence device.

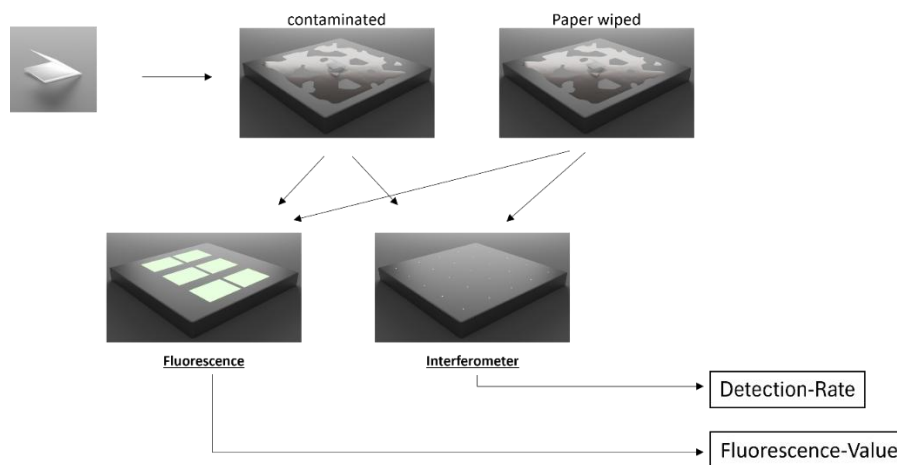


Figure 1: Experiment 1 Procedure

Experiment 2

While the interferometer is highly sensitive to surface topography, it cannot reliably measure film thicknesses below 1.5 μm . However, such thin contaminant layers can still be detected qualitatively using fluorescence spectroscopy. To establish a quantitative reference for these thinner films, a third technique – gravimetric analysis (weighing) – was introduced.

Due to the use of cut paper towel pieces as a distribution medium for the oil, the absorption rate into the paper was unknown. To account for this variable, each paper piece was weighed before and after the contamination process to determine the actual amount of oil transferred to the specimen. A total of 9 measurement batches were conducted.

Additionally, a separate series of 30 measurements was conducted to determine the mean weight of 1 μL of oil, providing an estimate of its density. Using this density, along with the measured mass of oil on the specimen surface, an estimated film thickness could be calculated. This value was then compared to the results from the interferometric and fluorescence measurements to explore potential correlations.

Procedure Overview:

1. Initial Cleaning
 - a. Measurement
2. Contamination
 - a. Measurement

Measurement Batches and Oil Volumes:

Measurement	Oil volume
1-3	1 μ L
4-5	2 μ L
6-9	3 μ L

Table 1: Measurement Batches and Oil Volumes

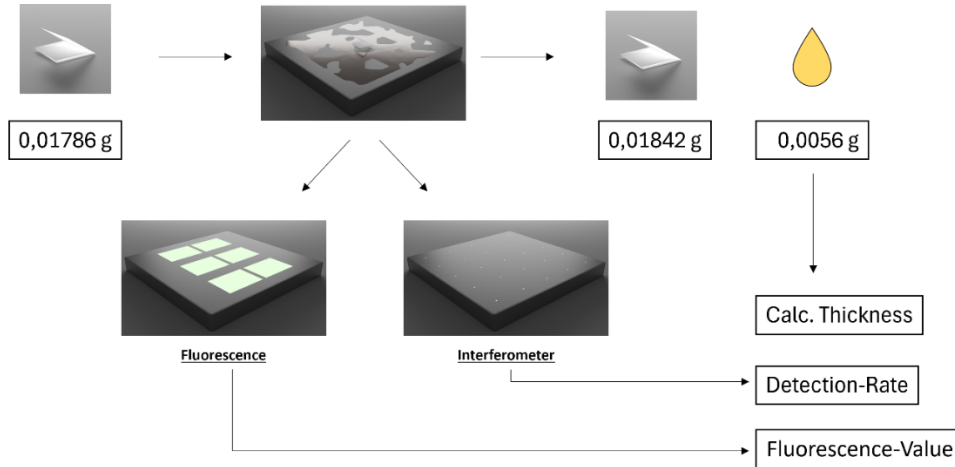


Figure 2: Experiment 3 Procedure

Experiment 3

To minimize the influence of variables, such as absorption rate of the paper piece, a different contamination – dilution – method is used. Oil and ethanol were mixed in a flask, through weighing the used oil and ethanol, a ratio for the mix was determined. The mixture was then poured over the surface without overflowing on the edges, so that 100% of the used mix was on the surface. Over the duration of approximately 10 min the ethanol evaporated completely, leaving the oil on the specimen. The oil is distributed almost equally, the surface tension on the edges seemed to influence the distribution.

Steps for this procedure:

1. Initial Cleaning
 - a. Measuring
2. Mix dilution
 - a. Weighing dilution
3. Contamination
 - a. Weighing dilution
 - b. Measuring after ~10min

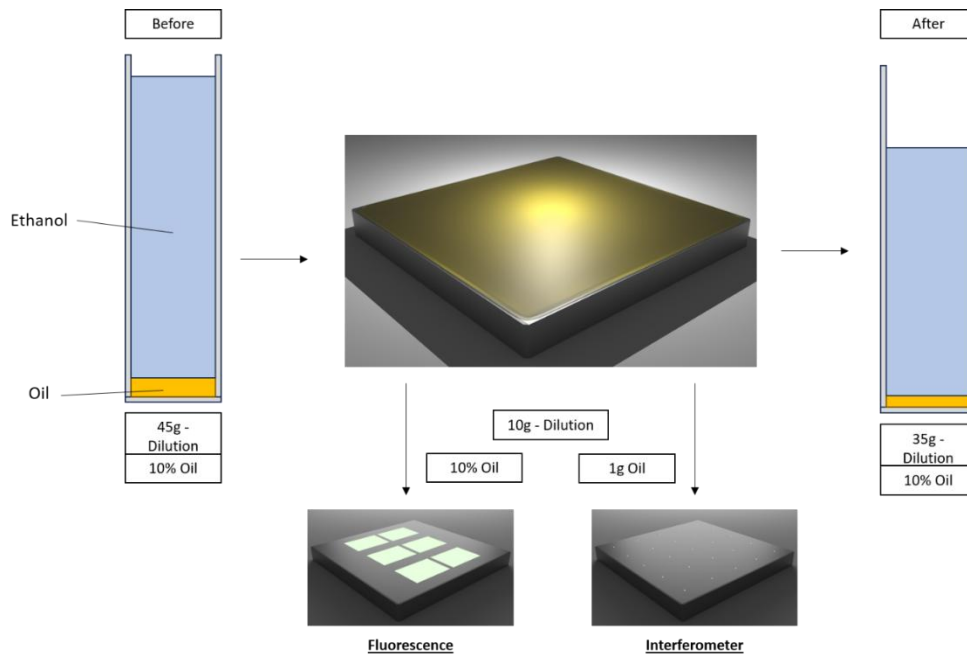


Figure 3: Experiment 3 Procedure

Experiment 4

This experiment is used to generate a connection between the tensile tape-test, the interferometer and the fluorescence. For this, the steel plates 53×315 mm and the coated steel plates from Scania are used. The contamination is performed the same way for each oil and plate.

Steps:

1. Initial Cleaning
 - a. Measuring
2. Contaminating
 - a. Measuring
3. Tape application
4. Testing

Experiment 5

The fifth experiment is equal to the fourth, the only difference are the fewer oils and the tap, which is substituted to the tape used by Scania in manufacturing.

2.5.3 Data processing

Interferometer

Each measurement cycle generates 25 measurements, each saved in a separate file. All files from each test are imported into MountainsLab and processed as the following: Non-Measured Points are extracted from each Surface. Those indicate how many points of the 1.000.000 possible points are measured. The values indicate if the surfaces are clean, or film contaminated. If the film-thickness is thinner than $1.5\mu\text{m}$ the detection rate drops significantly. The following figure displays an example for detection-rate, left: clean; right: contaminated. The 'Bottom Surface' stands for the surface measured by a second reflection on the same location. (MountainsLab®, 2025)

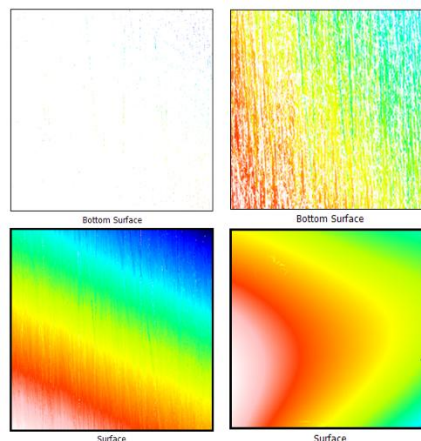


Figure 4: Detection-rate: Clean vs. Contaminated

The third surface, which is the calculated difference between the first and the second surface, contains the film-thickness. This surface contains thickness values depending on the detection rate of the other surfaces. Depending on the detection rate the non-measured points were filled with zero-values (detection rate $<30\%$) or with the mean value of the detected value. Hence the Mean-Thickness was calculated and added to the extracted values. Finally, the values extracted from the measurements were exported into a .csv file. All the 25 measurements and its values were summarized into one mean value and used to compare to the other test iterations.

Fluorescence

The data processing for this technique is much simpler as each measurement gets saved into the cloud and receives basic processing (mean fluorescence value). The data was exported into a .csv file. Like the interferometer data, all iteration measurements are summarized into one mean value.

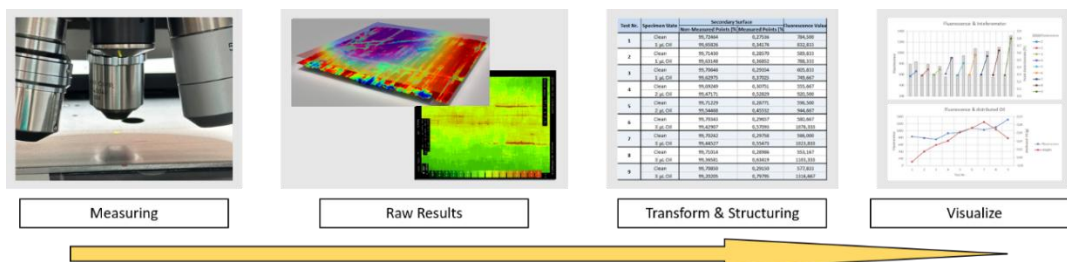


Figure 5: Measuring - Data processing

2.6 Tape Testing

Following the previous chapters, which focus on methods to quantify contamination levels, this section presents a practical evaluation of how such contamination affects adhesive performance. Tape peel testing was selected as the primary method to assess the impact of various chemical contaminants on adhesion strength. By applying a controlled amount of contaminant to test plates and measuring the peel force of adhesive tape, the goal was to establish whether specific contamination levels still allow for sufficient bonding. This method directly supports Scania's need for a functional threshold that ensures adhesion reliability, even when the exact contaminant is unknown.

2.6.1 Tools

The experimental setup for tape adhesion testing consisted of a tensile tester integrated with a custom-designed 90° peel fixture, allowing for controlled and repeatable measurement of peel forces. The testing procedure was based on standard tape peel tests described by (ADMET, 2011), with the Single-Coated 90-Degree Angle test selected as the most suitable method for this study. Due to the range limitations of the tensile tester, inline and 180-degree tests could not be performed. The setup and procedure were designed to align as closely as possible with relevant test standards, including those outlined by (ASTM, 2003).

Tensile tester

The tensile tester used for the tape pull-off tests was an Exceed® Electromechanical Test System, Model E45, from the company (MTS Systems, 2025). This model is equipped with a standard load cell rated up to 600 kN. In order to have a better measuring resolution, a second load cell for more precise measurements was added to the setup. The specific loadcell used was the MTS Force Transducer, Model BSS-XS-1t. This reduced the functional testing distance of the machine, making it impossible to perform any inline tests.

Tape test jig

When pulling off tape from a plate at 90 degrees, it is important that the plate moves forward while the tape is pulled off at a 1:1 ratio. Figure 6 shows the CAD model of the tool that was built to carry out the 90-degree tape pull-off test. The tape (blue in Figure 6) is applied to the test plate and clamped onto the sliding part of the jig. The loose side of the tape is clamped in and connected to the moving clamp of the tensile tester. A rope is connected to the moving part as well and runs over a pulley to the back of the slide. This ensures a constant 90 degree pulling angle by pulling the test plate forward while the tape gets pulled off. It is important to note that the end of the rope is connected below the load cell and thus does not affect the test results. On the other side of the jig, the slide is pulled back to its starting position with an elastic band to make sure the rope cannot pull the slide too far forward. The real life version can be seen in Figure 6.

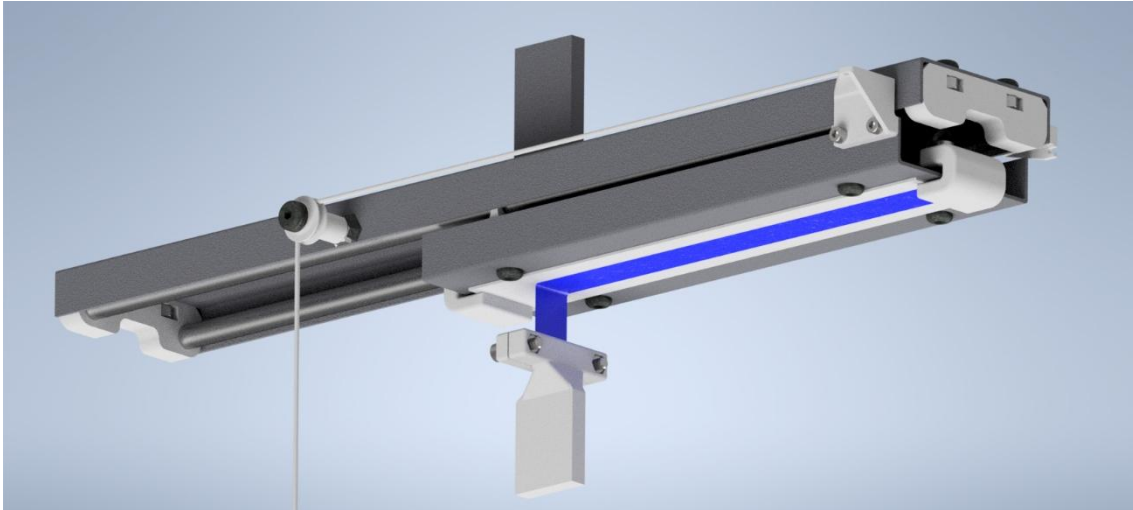


Figure 6: Tape Test CAD Model

Software

The system's standard MTS TestSuite™ software was enhanced with a specialized testing protocol fine tuned specifically for this application. Key modifications were implemented in the testing protocol to address the unique requirements of adhesion measurements on contaminated surfaces. The peel speed was carefully optimized to ensure reliable data collection. The automatic break detection function was intentionally disabled to prevent premature test termination that could occur with low-adhesion samples. This adjustment proved critical for obtaining complete force-displacement curves across all test conditions.

Probes

Two distinct types of test specimens were prepared for evaluation. The primary test samples consisted of coated plates sourced directly from Scania's battery production line. These parts are steel plates with polymer coatings applied to both sides. All plates were cut to standardized dimensions (53 × 315 mm) matching the test fixture requirements. For comparative analysis, uncoated steel plates with identical dimensions were included in the test to link the tape tests to the measurements, as it was impossible to get results from some techniques on the coated plates.

Tapes

The experimental program evaluated two tape variants with different material properties. The principal test series used Scania's insulation tape, representing the actual material implemented in battery pack assembly. Due to limited availability of this tape, most of the tests were conducted using commercial clear adhesive tape (Scotch Tape). This approach allowed comprehensive parameter studies while conserving the specialized insulation tape for final validation measurements. Due to the nature of the Scotch tape, the full width (48mm) was used. It was simply impossible to cut the tape to the standardized 24mm. This did not result in any problems as the probes and contaminated sections were wide enough and direct data from the two tapes was not compared.

Chemical Contaminants

Several chemical substances were selected to simulate realistic surface contamination scenarios encountered in battery module assembly environments. These contaminants represent a range of lubricant and cutting fluid types commonly found in industrial processing, as well as a household reference oil. Each contaminant was applied to the test substrates in a controlled manner to assess its impact on tape adhesion. Table 2 provides an overview of the selected substances, including their technical names and typical industrial applications. While this is not technically true for all of them, these contaminants will be referred to as oils.

Short name	Technical name	Industrial application	Reference
Klübertec	Klübertec CM 6-100	Klübertec CM 6-100 is a high-performance process oil used in cold forming, precision blanking, and metalworking of various metals	(OilOnline, 2025)
BioCut	BIOCUT 30E	Biodegradable cutting fluid for metalworking processes like milling, drilling, and turning.	(CHEMIROL AB, 2022)
Shell	Shell Tonna S3 M 68	Hydraulic and slideway oil for machine tools and precision machinery.	(Univar Solutions AB, 2023)
Cutting	Unimate Cutting Fluid	General-purpose cutting fluid for CNC machining and manual metal cutting operations.	(Clemondo AB, 2018)
WD 40	WD40	Multi-use lubricant and water displacer, used for cleaning, rust protection, and lubrication.	(WD-40 Company, 2019)
Olive	Olive oil	Not used industrially; included here as a reference contaminant due to its common household use.	

Table 2: Chemical Contaminants

2.6.2 Procedure

The tape adhesion testing followed a standardized protocol based on the ASTM principles, divided into three phases:

Tape application

The insulation tape was cut to 24 mm width. Due to the fixed width of the Scotch tape variant, this trimming step was not carried out for those specimens. Each tape strip was carefully applied along the plate's full length, extending beyond the contaminated zone. This was not possible for the insulation tape due to the size of the tape sheets received from Scania. Therefore each tape strip was applied 60 mm behind the contaminated area (0 – 100 mm). This can be seen in Figure 7. Using a plastic scraping tool to apply the tape ensured a bubble-free adhesion by systematically removing air pockets. This step guaranteed uniform contact pressure across the entire bonded area.



Figure 7: Tape Application, Insulation Tape

Probe mounting

The prepared plate was secured in the test jig's sliding carriage, with the contaminated region positioned at the predetermined start point. This alignment was calibrated during initial fixture setup and maintained constant for all following tests to ensure positional consistency. The free tape end was manually peeled back to the measurement origin point, then clamped in the tensile tester's moving crosshead. Precise angular alignment was verified visually to maintain a 90° peel geometry throughout testing. This setup can be viewed in below in Figure 8.



Figure 8: Peel Test Setup

Perform Peel Test

The MTS system executed the peel test at a controlled rate of 5 mm/s, maintaining constant velocity throughout the entire test span. Force-displacement data was recorded at 10 Hz sampling frequency, capturing the full adhesion profile across both contaminated and clean surface sections. Each test concluded automatically upon reaching the predetermined displacement limit, with raw data saved for later processing.

2.6.3 Data Analysis

The experimental data was systematically organized into nine test categories, with each test comprising multiple peel test runs. All data from individual test runs within a given test were compiled and processed in a dedicated Excel file for that test series. The initial test series primarily served to establish appropriate testing parameters and develop an effective data processing methodology. Therefore, Test 9 - representing the finalized approach - will be described in detail to illustrate the complete analysis procedure.

Data Preparation

The raw force-displacement data exported from the MTS software contained significant high-frequency fluctuations due to the elastic nature of the tape and dynamic peel characteristics. To address this, the first processing step applied a 7-point moving average filter to smooth the data, where each point became the average of itself plus three preceding and three subsequent datapoints. This filtering technique effectively preserved the underlying adhesion trends while eliminating noise.

A critical normalization step was then performed to enable meaningful comparisons across different test runs. Clean reference plates of each substrate type were tested to establish baseline adhesion levels. For every test run, the average load during the initial 10-second stabilization period was calculated and compared to the corresponding clean plate reference. The resulting offset value was applied to the entire dataset for that run, effectively aligning all baselines to a common reference point.

Data Comparison

The processed data was systematically compared through multiple stages. First, test runs examining the same tape and oil combination were grouped together, with their data averaged to produce more representative adhesion profiles. While the sample size of two tests per condition is not enough, due to time constraints this approach still provided valuable insights into adhesion trends.

Separate worksheets were created to compare results between the two substrate types - coated industrial plates versus uncoated steel references. This comparison highlighted how the polymer coating influenced adhesive performance under various contamination scenarios.

Finally, summary graphs were generated to visualize the relative effects of different oil contaminants. These plots presented data separately for each substrate type, enabling clear comparison of how various oils impacted adhesion strength.

3 Theory

This chapter examines fundamental concepts of surface cleanliness and its impact on industrial processes, focusing on contamination effects in welding and adhesion. It reviews measurement techniques, international standards, and research papers about contamination's influence on laser welding and adhesive bonds.

3.1 Chemical Cleanliness

3.1.1 Cleanliness

Cleanliness, in the context of manufacturing and surface engineering, refers to the state of a material being free from contaminants—unwanted substances that can adversely affect its performance, durability, or compatibility with subsequent processes such as welding, adhesion, or coating. Contaminants can originate from human handling, machining fluids, environmental exposure, or residual processing chemicals, and their presence can lead to significant functional defects (Mittal, 1979).

3.1.2 Cleanliness Types

Cleanliness is broadly classified into three categories, each associated with distinct contaminant types and measurement methodologies (ISO, 2017).

Particle Cleanliness:

Refers to solid contaminants such as dust, metal shavings, or fibers. These particles are typically detected via visual inspection, microscopy, or gravimetric analysis. In critical applications like battery assembly, particulate residues can cause electrical shorts or mechanical interference.

Molecular Cleanliness (Chemical Cleanliness):

Involves thin films of organic residues (e.g., oils, greases, silicones) adsorbed onto surfaces. These contaminants are often invisible to the naked eye but can severely compromise adhesion or welding quality.

Ionic Cleanliness:

Relates to inorganic residues like salts or fluxes, which can promote corrosion or electrochemical reactions. Ionic contamination is quantified through resistivity testing or ion chromatography.

3.2 Measurement Techniques

To measure chemical contamination on the manufacturing surface, several quantitative techniques are used in research and industries. These methods vary in resolution, scalability, and applicability depending on material properties and contamination types. Below in Table 3, seven key techniques are compared based on their function, measurement capabilities, and practical trade-offs:

Technique	Function	Measurement Type	Resolution	Scalability	Pros	Cons
Interferometry	Measures surface topography and thin-film thickness via light interference.	Optical (nm-scale films)	~1.5 μm	Lab-scale	High resolution; non-contact.	Sensitive to vibrations; complex setup.
Ellipsometry	Determines film thickness and optical properties using polarized light.	Optical (nm-scale films)	~1 nm	Lab-scale	Ultra-high resolution; works on opaque materials.	Requires smooth surfaces; expensive equipment.
Ultrasonic Sound Analysis	Detects subsurface contaminants via sound wave reflection/attenuation.	Acoustic (μm -mm layers)	~10 μm	Industrial	Non-destructive; works on rough surfaces.	Lower resolution; limited to thick films.
Fluorescence Spectroscopy	Identifies organic residues (e.g., oils) via UV-excited emission.	Spectral ($\mu\text{g}/\text{cm}^2$)	~0.1 $\mu\text{g}/\text{cm}^2$	Lab/field	High sensitivity; rapid screening.	Requires fluorescent contaminants.
Gravimetric Analysis	Weighs samples before/after cleaning to calculate contaminant mass.	Mass (mg)	~0.01 mg	Lab-scale	Simple; follows ISO/ASTM standards.	Destructive; low spatial resolution.
Contact Angle Measurement	Assesses wettability to infer surface energy/cleanliness.	Angular (degrees)	~1°	Lab/industrial	Fast; inexpensive; portable tools available.	Indirect measure (requires calibration).
FTIR	Identifies organic contaminants (e.g., oils, greases) by molecular bond vibrations.	Spectral ($\mu\text{g}/\text{cm}^2$)	~0.1 $\mu\text{g}/\text{cm}^2$	Lab/industrial (portable units)	Fast, non-destructive Detects functional groups (C-H, O-H)	Limited to surface films >100 nm Requires reference libraries
XPS	Measures elemental composition and chemical states of surface atoms (top 1-10 nm).	Elemental (atomic %)	~0.1 at %	Lab-scale	Quantifies oxidation states Detects trace metals/organics	Destructive (vacuum required) Slow; expensive equipment

Table 3: Measurement Techniques

3.3 Standards

Quantifying chemical contamination in manufacturing requires standardized methods to ensure reproducibility and quality control. While several international standards about surface cleanliness exist, most focus on cleanroom environments or generalized contamination thresholds rather than industrial applications like Scania’s battery assembly. The following Table 4 summarizes key standards reviewed for this thesis and their limitations in addressing Scania’s specific challenges with welding defects and tape adhesion failures:

Standard	Scope	Key Parameters	Relevance to Thesis	Limitations
ISO 14644-10:2022 (ISO, 2022)	Cleanroom surfaces	- SCC grading ($\mu\text{g}/\text{m}^2$ to ng/m^2) - FTIR/XPS/gravimetric methods (Annex D)	Provides logarithmic contamination scales adaptable for industrial use.	No thresholds for oils/greases in welding/adhesion.
ASTM E21.65 (ASTM International, 2021)	Thin-film measurement	- Gravimetric analysis ($\mu\text{g}/\text{cm}^2$) - Non-destructive techniques (ellipsometry)	Useful for quantifying oil film thickness on metals (e.g., aluminum busbars).	Requires calibrated lab equipment; no adhesion criteria.
ASTM D7334-08 (ASTM, 2022)	Surface wettability	- Contact angle measurement - Surface energy calculation	Indirectly assesses cleanliness via wettability (e.g., polymer-coated steel plates).	Qualitative; requires correlation with contamination levels.
ASTM E1078 (ASTM, 2020)	Surface cleaning validation	- Solvent extraction - Particulate/organic residue analysis	Validates cleaning processes (e.g., isopropanol wiping).	Limited to post-cleaning verification, not in-process.

Table 4: List of Standards

Where These Standards Fall Short

Cleanroom Bias: ISO and ASTM methods prioritize particulate or molecular contamination in controlled environments, not industrial settings with machining oils/greases.

Lack of Process-Specific Thresholds: None define acceptable contamination levels for laser welding or tape adhesion on polymer-coated steel.

Measurement Constraints: Techniques like XPS or gravimetry assume lab-scale samples, not large battery components.

This gap forces us to adapt protocols from these standards and define practical contamination thresholds.

3.4 Welding

The only article found related to chemical cleanliness and laser welding is the research article:

Effect of surface cleaning on seam quality of laser beam welded mixed joints
(Kenéz, Földes and Lubl6y, 2023)

The study tests seven different cleaning methods such as isopropyl, acetone or Sand blasting and welds teeth onto the drill bit. With a break-off test the measured force is used to assess the influence of the cleaning methods. When comparing the results, no significant difference between the cleaning methods was found. Only ice-cleaning, which is described as a unstable process, showed a difference with higher required forces. The study must be viewed with caution, since the researchers did not evaluate the cleanliness state before and after cleaning, which gives no conclusion on whether the specimen was clean before or rather contaminated.

3.5 Adhering

For the tape adhesion section of this thesis, two key papers were reviewed:

Effect of surface contamination on the durability and strength of stainless steel - polyisobutylene pressure-sensitive adhesive bonds (Kostyuk et al., 2019)

Effects of residual oils on the adhesive properties of polymer-metal interfaces (Kwon, Yoon and Hwang, 2019)

3.5.1 Key Insights from Reviewed Papers

Both papers show that oil contamination weakens adhesive bonds by creating a weak layer at the interface. Even thin oil films (2.5–7µm) reduce strength by 50–90%, regardless of the adhesive type. This happens because the oil plasticizes the contact area, making it easier for the bond to fail.

Adhesion can recover over time, but only if the oil and adhesive are chemically compatible. Miscible oils, such as mineral oil in polyisobutylene (PIB)-based adhesives, can disperse into the adhesive matrix, allowing for partial or even full recovery of adhesion strength. In contrast, incompatible oils, like sunflower oil, remain at the interface and inhibit bonding, often leading to permanent adhesion loss. Interestingly, in some cases, compatible oils not only allowed recovery but appeared to enhance adhesion performance beyond the clean reference, possibly by plasticizing or improving surface wetting of the adhesive layer.

Solutions exist but depend on the system. Adding fillers helps by absorbing oil, while proper surface cleaning prevents contamination. The best approach varies based on the oil type, adhesive, and material—no universal fix works for all cases.

3.5.2 Limitations for the Research

While these studies provide valuable insights, their findings may not directly translate to this specific application. The papers examined stainless steel and specific adhesives, while this thesis focuses on polymer-coated plates and different tapes. This material difference could change how oils affect adhesion, since polymer surfaces might interact with contaminants differently than metals.

Another limitation is the type of oils tested. The studies used vegetable and mineral oils, but industrial environments often involve more complex contaminants like silicones or machining fluids. These might behave differently, potentially causing stronger or weaker adhesion problems.

Finally, the studies do not define clear contamination thresholds for industrial applications. While they show some results for their specific applications, it still needs to be determined what oil levels are acceptable for reliable tape adhesion in this thesis.

3.6 Literature Conclusion

The reviewed literature reveals significant gaps in understanding how chemical contamination affects industrial adhesion and welding processes. While general principles of contamination effects are established, research specifically addressing applications—including tape adhesion on coated plates and laser welding in constrained geometries—remains limited.

Existing standards and studies predominantly focus on cleanroom environments or idealized material combinations, leaving a lack of practical guidelines for real-world manufacturing scenarios. The absence of defined contamination thresholds for critical processes like busbar welding or polymer-to-tape bonding highlights the need for targeted research.

4 Results

Within this chapter, the results and findings from the Measurements and the Tape Test are displayed and discussed.

4.1 Measurement Results

In the following section, generated results from the Measurements will be displayed and followed by a short discussion.

4.1.1 Experiment 1

Diagram 1 showed the different iteration and cleanliness states (cleaned, contaminated, paper wiped). Markers with line represent the measurements with the interferometer (detected points % of 1.000.000) and the columns represent the fluorescence values corresponding to the interferometer results.

This graph displays all mean values for each batch, a total of 27 measurements from both techniques which are linked with a linear trendline. Two points are further apart from the others. Those points have the highest amount of oil volume applied.

Discussion

When analyzing the diagram and the relationship between those values, the detection-rate is directly related to the fluorescence values. Furthermore, cleaning the contamination with just a paper towel results in a significantly cleaner surface compared to contaminated surface.

When studying Diagram 2, which shows the relationship between the two techniques and acquired values, the relationship between the techniques is clearly noticeable. For the two points further apart, it is assumed that the absorption of the paper has reached the maximum amount. As a result of that more oil remained on the specimen.

Summarized it can be stated that there is a linear relationship between the measurements which means that both machines can detect contamination qualitatively. Regarding quantitative measurements both instruments are not applicable, due to the device limitations. (Appendix: Experiment 1 – Result-Values)

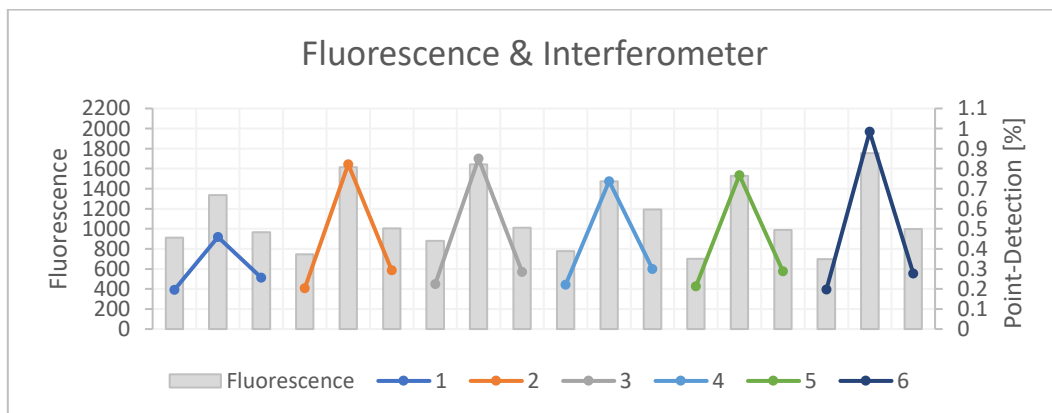


Diagram 1: Exp. 1 - Fluorescence & Interferometer

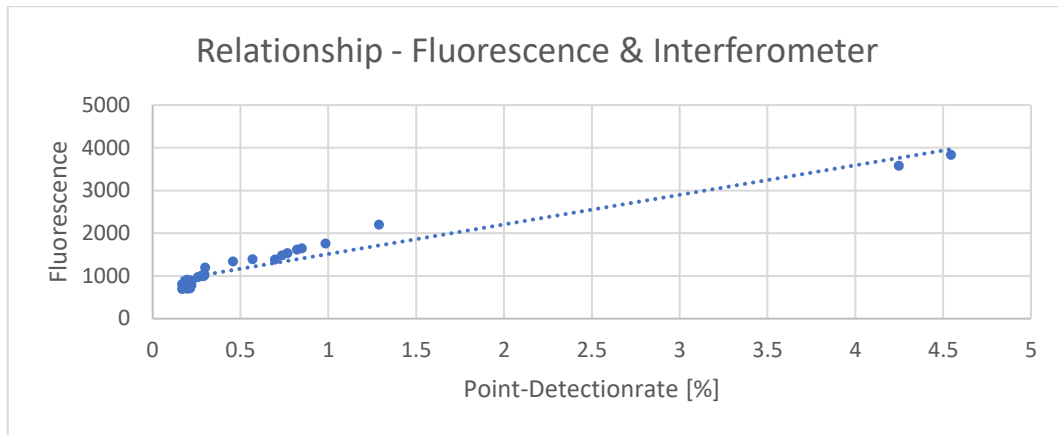


Diagram 2: Exp. 1 - Relationship - Fluorescence & Interferometer

4.1.2 Experiment 2

Diagram 3 shows the relationship between the fluorescence and the interferometer for each of the 9 conducted measurement batches.

Diagram 4 shows the mean-values of all 9 batches. The two curves display the rise of the fluorescence values over different applied oil volumes, and the calculated thickness based on the remaining oil volumes for each batch.

Discussion

Diagram 3 shows the same relationship as Diagram 1 in the first experiment. This indicates a similar correlation between the techniques, which can be seen as a baseline or referents on the correctness of the test.

In Diagram 4, both lines should show a similarity in curvature. But no real correlation can be determined between those curves, fluorescent values rise, and calc. thickness rises/shrinks with no visible relation.

Additionally, as some batches were executed the same way (Appendix: Experiment 2 – Result-ValuesDiagram 11: Fluorescence Deviation), these similarities should be visible in the measurements. Looking at the graphs, except for the first 3, the values are not very similar. This could be seen as a sign that the chosen distribution method is not very reliable.

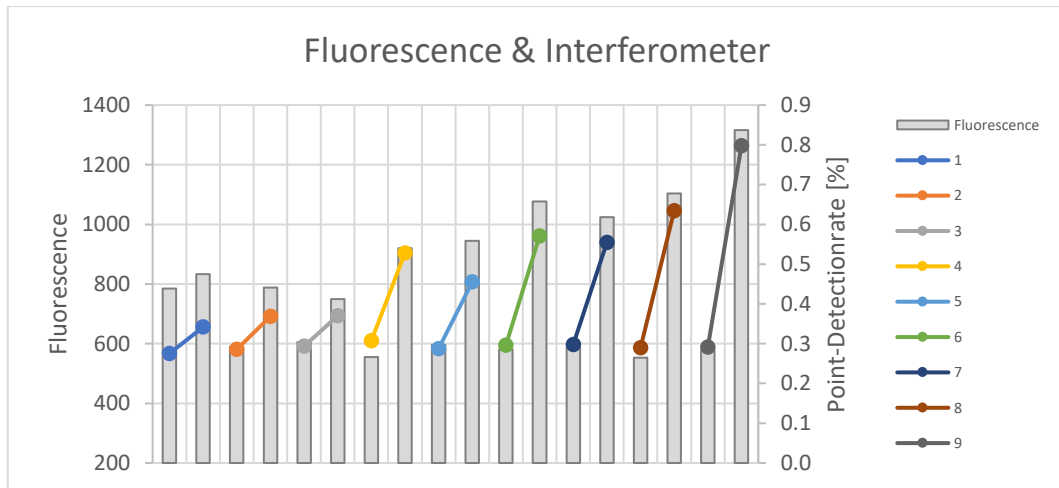


Diagram 3: Exp. 2 - Fluorescence & Interferometer

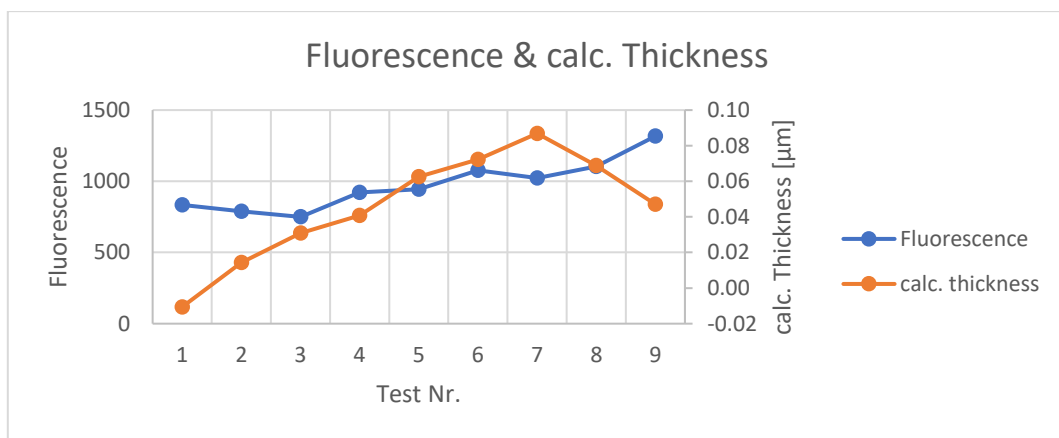


Diagram 4: Exp. 2 - Fluorescence & calc. Thickness

4.1.3 Experiment 3

Table 5 shows the used dilutions and the related calculation and measurements. The calculated thickness is higher for all tests compared to the measured thickness. The only exception is the dilution where the thickness approaches the interferometer limit.

To set the measurements into a relation, Diagram 5 **Error! Reference source not found.** is used. It displays the relationship between the two thicknesses and fluorescence values.

Discussion

With the excel trendline-feature a linear correlation can be seen. It is also visible that there is a difference between the curve's gradient and the starting point. When studying the generated equations and the measurement points for the two curves, the green one does align the best with the data. The blue points display the relation between the measured thickness and the fluorescence-values, those must be viewed carefully due to having only ~50% detection rate. But this shows that through this method, a correlation to the other measurement techniques can be drawn.

	Dilution			
Number	1	2	3	4
Ratio [%] of Oil	8.87	5.39	0.60	5.39
Weight based Thickness [μm]	24.47	12.19	1.46	7.56
measured Thickness [μm]	16.74	8.27	2.11	6.76
Fluorescence	200833.33	98800.00	11966.67	63400.00

Table 5: Exp. 3 - information & results

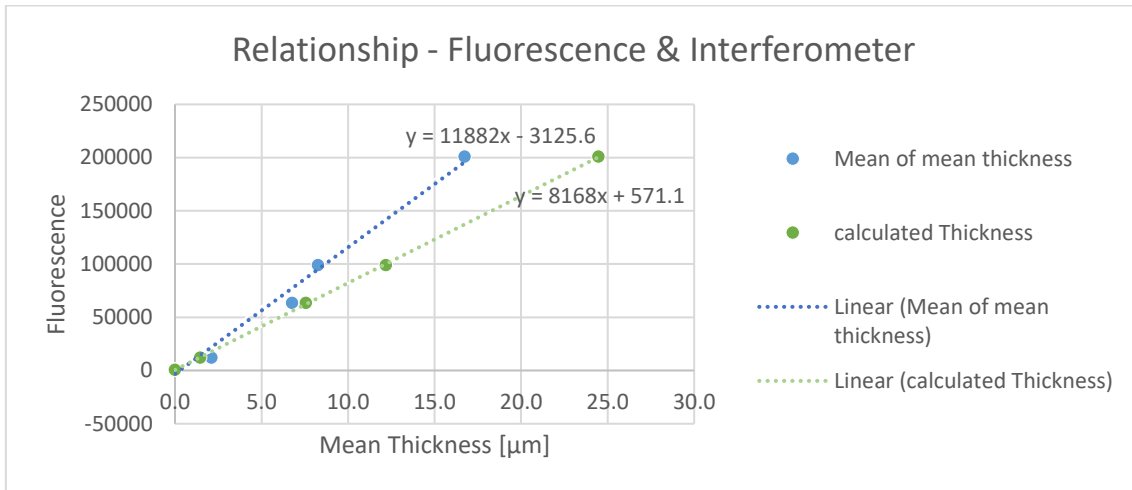


Diagram 5: Exp. 3 - Linear connection

4.1.4 Experiment 4 & 5

Experiment 4 & 5 is for connecting the tape test and the measurements, the related data is found in the Test-section or in the appendix.

Discussion

The conclusions which can be drawn from the measurement-side are that measuring the coated plate with fluorescent is not feasible. The coating has a very high fluorescence value (<300k) which makes it hard to detect thin-film contamination. As a result of that, the coated plates were only measured with the interferometer. Additionally due to the fluorescence of the different oils, a statement of cleanliness based solely on measured fluorescence values is not possible. (Appendix: Experiment 4 – Result-Values)

4.2 Tape Test results

In total, 90 tape pull test runs were performed, distributed across nine distinct test series. An overview of all tests, including specific parameters and conditions, is provided in Appendix E Tape Test Logbook. However, all relevant conclusions can be drawn from the final two series: Test 8 and Test 9.

Test 8 evaluated six different chemical contaminants along with a clean reference condition. Each scenario was tested through four runs—two on polymer-coated plates and two on uncoated steel plates. This test series was conducted using commercial Scotch tape due to the limited supply of the insulation tape.

Test 9, in contrast, was performed with Scania’s actual insulation tape to reflect real-world application scenarios. Due to the restricted availability of this material, only three contaminants and one clean condition were included. As with Test 8, each condition was tested using both coated and uncoated probes.

In both test series, 2 microliters of contaminant were applied uniformly over the same defined contamination area. Due to the challenges in accurately measuring or controlling contamination thickness, the first two results are interpreted based solely on the added volume of chemical contaminant. The third result like the fluorescence measurements to the tape adhesion measurements.

The following sections present the key findings from these tests, structured according to two primary comparison categories: Different Substrates, Different Tapes, and Linking to Measurements.

4.2.1 Different Substrates

To investigate the effect of the substrate material on adhesive performance, two graphs from Test 8 were analyzed (Diagram 6 and Diagram 7). Both graphs were generated using data obtained with Scotch tape, and each displays adhesion force (y-axis) over time (x-axis). Every graph includes seven lines, corresponding to six chemical contaminants and one clean reference. The contaminated region in all tests spans approximately from 10 seconds to 30 seconds, reflecting the timeframe in which the tape was peeled over the pre-treated area.

The first graph presents results from the polymer-coated plates, while the second shows data from the uncoated steel plates. From visual inspection and comparison, it becomes evident that the base material has a substantial impact on adhesion performance.

On the coated plates, only one of the contaminants produced a clear reduction in adhesion force. Interestingly, three of the tested substances even resulted in higher adhesion values compared to the clean reference. In contrast, all contaminants on the steel plates caused a notable decrease in adhesion strength, with no cases showing improved performance.

The underlying causes of this material-dependent behavior are not yet fully understood. Factors such as surface energy, roughness, or interactions between the coating and the contaminants may be involved, but these aspects were not investigated further, as they fall outside the scope of this project. Instead, the focus remains on identifying worst-case scenarios to define a reliable adhesion threshold. Since Scania is not necessarily aware of which contaminant might be present in production, they require a method to verify whether contamination levels are sufficiently low—regardless of the specific substance. This means that any threshold for acceptable adhesion must be based on the worst-performing contaminant, ensuring robust adhesion performance even under unknown contamination conditions.

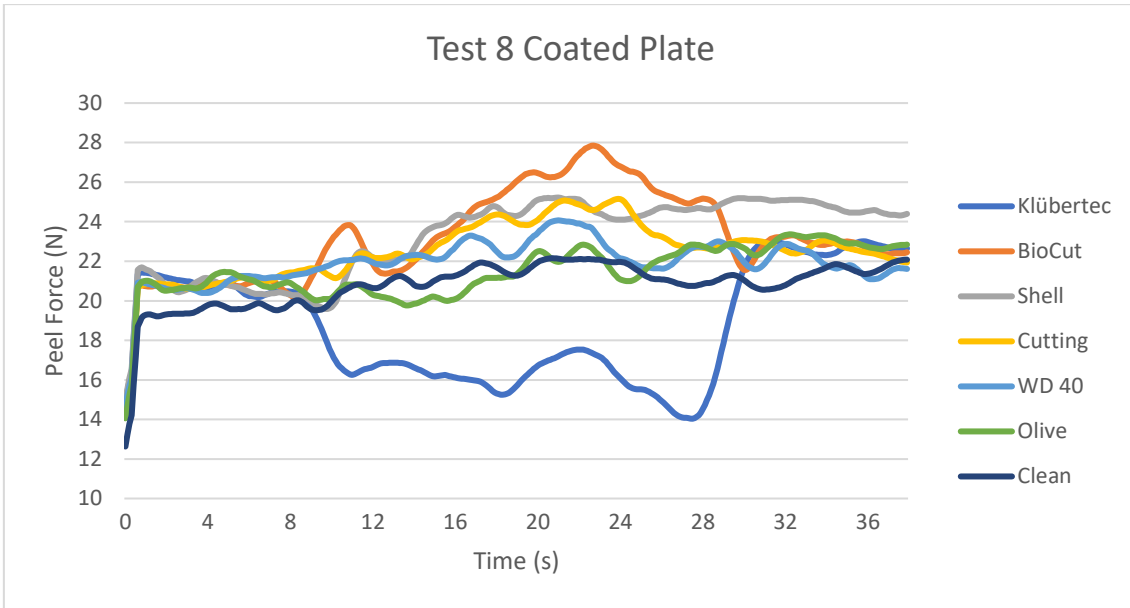


Diagram 6: Test 8: Coated Plates

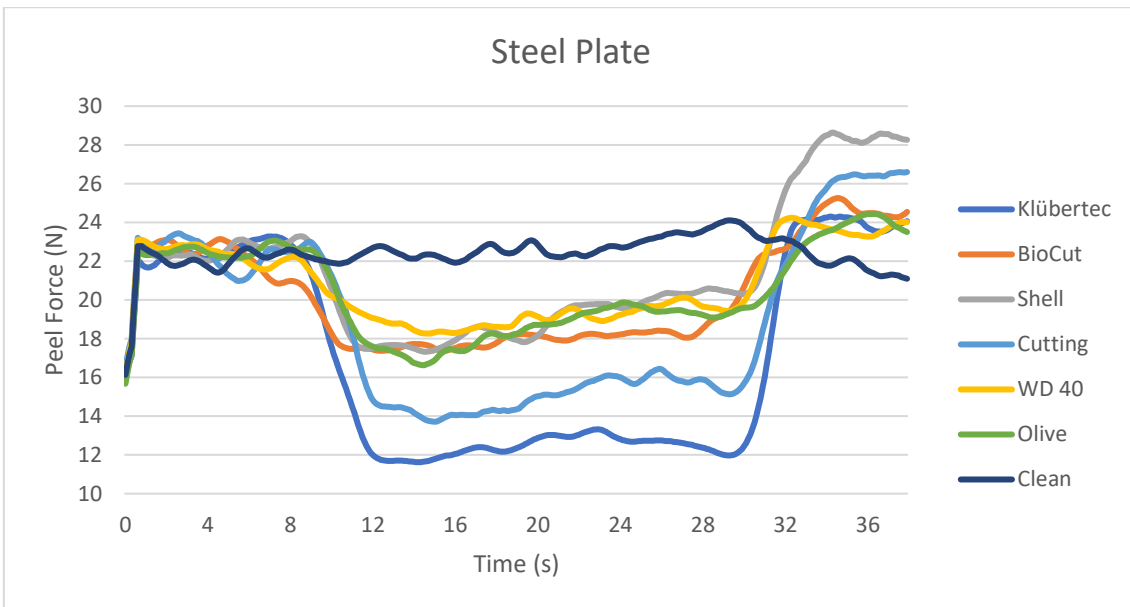


Diagram 7: Test 8: Steel Plates

4.2.2 Different Tapes

To examine the influence of tape type on adhesion performance, a combined graph (Diagram 8) was created comparing results from Test 8 (Scotch tape) and Test 9 (insulation tape). This graph includes three contaminants that were tested in both test series. Because the two tape types differ in both width and adhesion properties, a normalization procedure was applied to allow for meaningful comparison.

To achieve this, the baseline average (i.e., clean reference condition) from Test 9 was divided by the baseline from Test 8. The resulting scaling factor—approximately 0.58—was then used to multiply all adhesion values from Test 8. This method brought the Scotch tape data to a comparable level with the insulation tape results, enabling relative performance evaluation across both tape types.

Based on the adjusted graph, it can be concluded with reasonable certainty that the type of tape does not drastically affect the overall contamination trends. While there are small differences in absolute adhesion levels, the relative behavior between contaminants remains consistent. Specifically, Klübertec oil consistently produced a strong reduction in adhesion strength, while BioCut showed a clear improvement compared to the clean reference in both tape types.

It should be noted, however, that the sample size is limited, and the manual application method used in these tests may introduce variability. As such, results should be interpreted with caution. Nonetheless, the consistency observed in key trends suggests that conclusions regarding contaminant impact are not highly sensitive to the choice of tape.

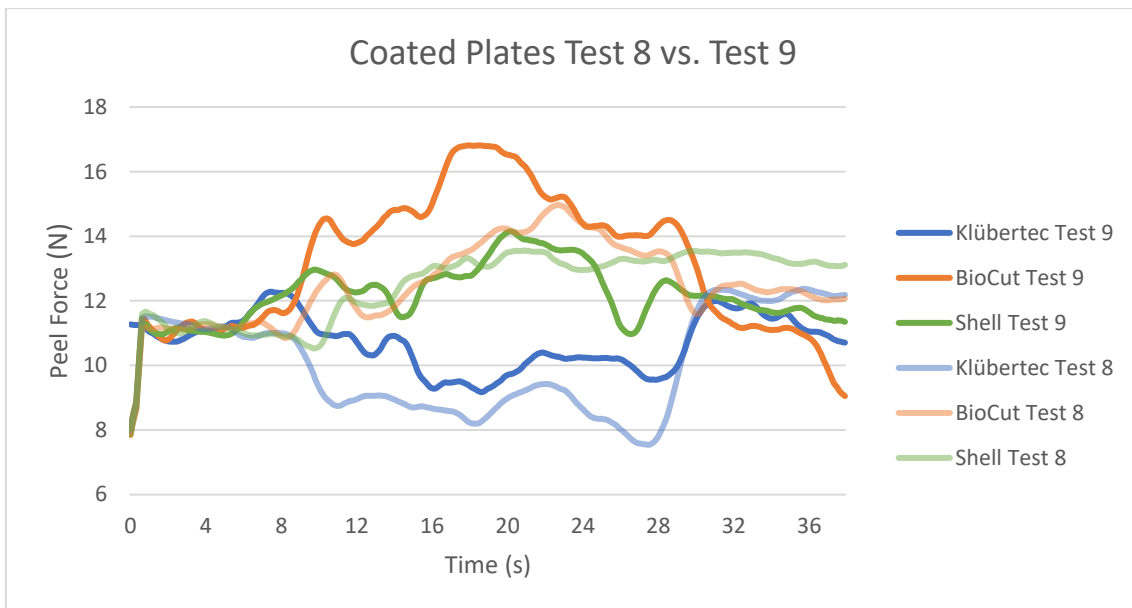


Diagram 8: Coated Plates: Test 8 vs. Test 9

4.2.3 Linking to Measurements

To explore the relationship between contamination level and adhesive performance, a combined diagram was created using data from Test 9, specifically for Klübertec oil applied to steel plates. This pairing was selected because steel substrates allow reliable fluorescence measurements, whereas coated plates do not yield consistent data due to interference from the surface treatment.

Diagram 9 shows the average fluorescence values and corresponding peel force values for both clean and contaminated regions across two separate test runs. While the data presented is limited to Klübertec oil and insulation tape on steel plates, similar trends were observed for all other oils and tape types tested on steel plates in this study.

The diagram clearly illustrates an inverse relationship: higher contamination levels, indicated by increased fluorescence intensity, directly correlate with lower adhesion strength. Even the subtle differences between the two test runs are reflected in the measurements, demonstrating both the sensitivity and consistency of the combined approach.

It is, however, very important to note that the adhesion values obtained from steel plates are not in line with those observed for coated plates, as discussed in chapter 4.2.1 Different Substrates. Therefore, this data cannot be directly applied to Scania’s specific use case, where insulation tape is adhered to coated surfaces. Nonetheless, the results remain relevant for other industrial applications where adhesive tapes are applied directly to steel parts, and they demonstrate the potential for linking surface cleanliness measurements to adhesive performance more broadly.

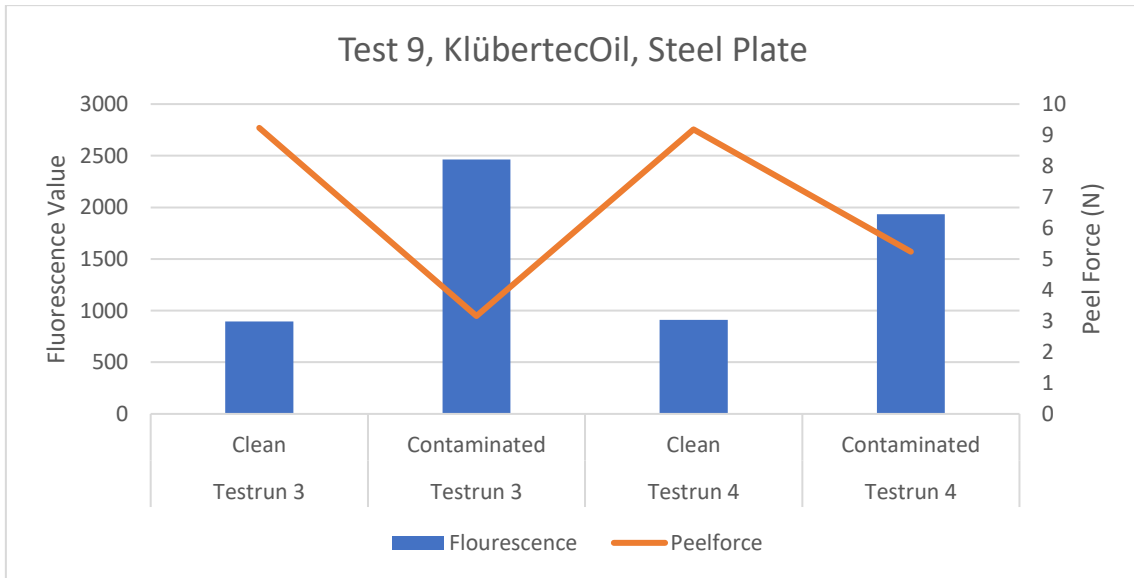


Diagram 9: Tape adhesion linked to Fluorescence values

5 Conclusion

After going through the test and the results, some conclusions can be drawn. While quantifying contamination sounds simple on paper, as soon as the limits of the interferometer are reached, and the contamination is unknown and the quantifying process gets more complicated. The combination of measuring with fluorescence and interferometry enables one to generate a correlation between the two techniques. But as the bottom contamination limit for the interferometer is reached, both methods are purely qualitative.

To convert the qualitative results into quantitative, a third technique must be introduced. In this case a dilution in combination with a scale was used (Experiment 3). The technique results in a calculated thickness based on the weight and dilution-ratio applied to the specimen. If now measured with the previous techniques the conversion can be made.

Apart from the techniques, the specimens have rather big influence on the measurements. Coated plates are a big challenge to measure due to having already a film applied (clear coat) and a very high base fluorescence value. This makes it very difficult to detect let alone measure. Rather than measure the contamination or control for contamination it is advised to focus on cleaning. By establishing a defined cleaning procedure, it is ensured that the parts are always clean despite initial contamination.

While fluorescence and interferometry can indicate the presence of contamination, a major limitation arises when the specific contaminant is unknown, as the influence on adhesion strength cannot be determined from measurement data alone due to the varying effects of different oil-substrate combinations.

Results from tape tests showed that some oils significantly reduce adhesion on steel plates while having little to no negative effect—or even improving adhesion—on polymer-coated substrates. The reasons behind these variations remain unclear. Factors such as surface energy, wetting behavior, or chemical interactions between the coating and the oil may play a role, but these were outside the scope of this study and would require further investigation.

Ultimately, while measurement techniques can help estimate contamination levels, the effect on adhesion cannot be reliably predicted without knowing both the contaminant type and the substrate. For practical applications like Scania's, this reinforces the need to define worst-case scenarios and base contamination thresholds on the most harmful oil-substrate combinations observed.

6 Critical Review

Economics

Setting requirements on surface cleanliness has a significant impact on economics. Undefined and uncontrolled surface cleanliness can lead to reworking or destroying the part. Both impact the cost of the production and might be avoided with the right requirements or quality controls.

Environmental

As previously stated, having no requirements will eventually lead to waste and rework. Either parts or the whole product might be thrown away or must be replaced. This can lead to a massive amount of waste generation and energy consumption.

Health and safety

As this thesis focuses on the application of insulation tape, the insulation aspect must be considered as a critical requirement. Any wrong application or non-application due to bad adhesion might lead to shortage and is a hazard to anyone working with the product, whether they are mechanics or workers at the production line.

Review and improvements

Despite achieving the overall research objectives, several methodological aspects could have been improved. The interferometer used was assumed to be suitable for thin-film measurements in the nanometer range, as advertised online, but was only capable of measuring films thicker than 1.5 μm . Earlier clarification of its limitations would have enabled better planning and possibly the integration of more suitable tools. The manual methods used for contamination distribution—particularly the use of pipettes and paper towels—introduced inconsistency, making repeatability and quantification difficult. A standardized application method, such as spraying or dip-coating, would have improved reliability. Additionally, the tape application process lacked force control, and the custom-built tape peel test rig showed some mechanical play, both of which may have affected measurement accuracy. A more rigid fixture or commercially available test setup could have ensured greater consistency. Finally, while the literature provided valuable insights, further exploration of industrial standards and advanced adhesion testing methodologies might have enhanced the depth and applicability of the findings. Overall, while the task was addressed effectively within the constraints, these refinements could have improved data quality and broadened the study's impact.

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Appendices

A. Experiment 1 – Result-Values

Test Nr.	Specimen State	Secondary Surface		Fluorescence Value
		Non-Measured Points [%]	Measured Points [%]	
1	Clean	99.80444	0.19556	910.500
	2 μ L Oil	99.54103	0.45897	1335.000
	Paper wiped	99.74312	0.25688	967.333
2	Clean	99.79634	0.20366	747.000
	4 μ L Oil	99.17810	0.82190	1615.000
	Paper wiped	99.70644	0.29356	1003.833
3	Clean	99.77637	0.22363	878.833
	6 μ L Oil	99.14999	0.85001	1641.667
	Paper wiped	99.71520	0.28480	1010.833
4	Clean	99.77912	0.22088	776.667
	8 μ L Oil	99.26265	0.73735	1473.333
	Paper wiped	99.70083	0.29917	1193.500
5	Clean	99.78635	0.21365	701.667
	10 μ L Oil	99.23246	0.76754	1528.333
	Paper wiped	99.71144	0.28856	989.667
6	Clean	99.80332	0.19668	697.333
	14 μ L Oil	99.01610	0.98390	1755.000
	Paper wiped	99.72231	0.27769	996.667
7	Clean	99.83110	0.16890	805.833
	16 μ L Oil	98.71084	1.28916	2200.000
	Paper wiped	99.70340	0.29660	1030.000
8	Clean	99.83180	0.16820	687.833
	20 μ L Oil	95.75177	4.24823	3573.333
	Paper wiped	99.43140	0.56860	1388.333
9	Clean	99.80300	0.19700	736.500
	24 μ L Oil	95.45397	4.54603	3831.667
	Paper wiped	99.30317	0.69683	1381.667

Table 6: Experiment 1 – Result-Values

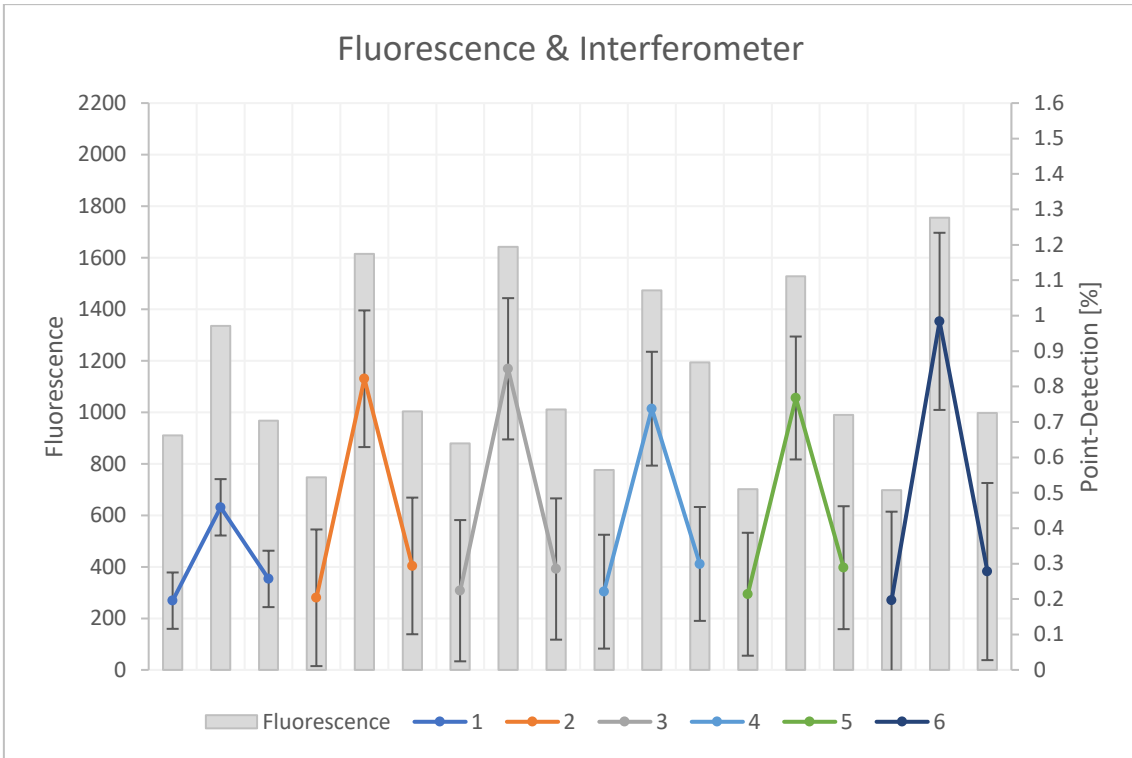


Diagram 10: Interferometer Deviations

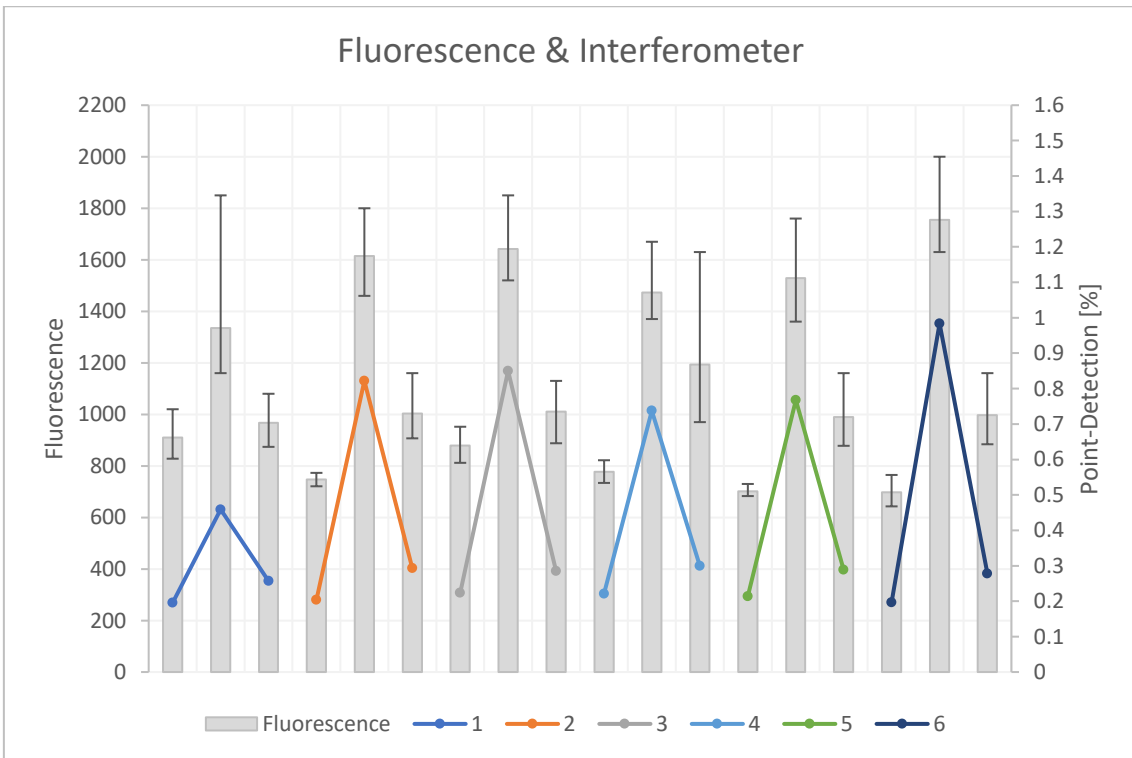


Diagram 11: Fluorescence Deviation

B. Experiment 2 – Result-Values

Test Nr.	Specimen State	Secondary Surface		Fluorescence Value
		Non-Measured Points [%]	Measured Points [%]	
1	Clean	99.72464	0.27536	784.500
	1 μ L Oil	99.65826	0.34174	832.833
2	Clean	99.71430	0.28570	589.833
	1 μ L Oil	99.63148	0.36852	788.333
3	Clean	99.70646	0.29354	605.833
	1 μ L Oil	99.62975	0.37025	749.667
4	Clean	99.69249	0.30751	555.667
	2 μ L Oil	99.47171	0.52829	920.500
5	Clean	99.71229	0.28771	596.500
	2 μ L Oil	99.54468	0.45532	944.667
6	Clean	99.70343	0.29657	580.667
	3 μ L Oil	99.42907	0.57093	1076.333
7	Clean	99.70242	0.29758	586.000
	3 μ L Oil	99.44527	0.55473	1023.833
8	Clean	99.71014	0.28986	553.167
	3 μ L Oil	99.36581	0.63419	1103.333
9	Clean	99.70850	0.29150	577.833
	3 μ L Oil	99.20205	0.79795	1316.667

Table 7: Experiment 2 – Result-Values

C. Experiment 4 – Result-Values

Oil Name	Specimen	Interferometer measured Points [%]		Fluorescence	
		Clean	Contaminated	Clean	Contaminated
Oil 1	A	3.652	3.219	35000.000	35250.000
	B	3.679	3.421	343250.000	341250.000
	E	0.245	0.455	896.250	2955.000
	F	0.213	0.294	910.750	2232.500
Oil 2	A	0.001	0.004	-	-
	B	0.000	0.003	-	-
	E	0.235	0.348	907.000	5377.500
	F	0.208	0.282	802.750	4027.500
Oil 3	A	2.775	2.777	-	-
	B	2.770	2.735	-	-
	E	0.170	0.381	1078.500	38500.000
	F	0.156	0.328	829.000	35725.000
Oil 4	A	2.400	2.186	-	-
	B	2.380	2.208	-	-
	E	0.248	1.158	843.750	1430.000
	F	0.323	1.052	1020.000	1872.500
Oil 5	A	1.981	2.001	-	-
	B	2.045	2.090	-	-
	E	0.241	0.516	863.000	9655.000
	F	0.186	0.301	757.500	8022.500
Oil 6	A	3.174	3.156	-	-
	B	3.210	3.176	-	-
	E	0.240	1.192	1000.500	1887.500
	F	0.193	0.597	874.250	1505.000

Table 8: Experiment 4 – Result-Values

D. Experiment 5 – Result-Values

Oil Name	Specimen	Interferometer		Fluorescence	
		measured Points [%]		Clean	Contaminated
		Clean	Contaminated	Clean	Contaminated
Oil 1	A	3.864	3.489	-	-
	B	3.851	3.367	-	-
	E	0.245	0.818	896.250	2465.000
	F	0.213	0.415	910.750	1932.500
Oil 2	A	0.001	0.009	-	-
	B	0.001	0.005	-	-
	E	0.238	0.927	900.500	8267.500
	F	0.208	0.420	893.750	5672.500
Oil 2	A	0.001	0.009	-	-
	B	0.001	0.009	-	-
	E	0.223	0.585	964.750	50725.000
	F	0.200	0.475	1060.000	46675.000

Table 9: Experiment 5 – Result-Values

E. Tape Test Logbook

		Tape	Plate	Plate type	Oil type	Oil V.	Application method	Sensor
Test 1	Testrun 1	Plastic	A	Coated	Klübertec	22,5	Saturated paper wipe	Big
	Testrun 2	Plastic	B	Coated	Klübertec	22,5	Saturated paper wipe	Big
	Testrun 3	Plastic	C	Coated	Klübertec	22,5	Saturated paper wipe	Big
	Testrun 4	Plastic	D	Coated	Klübertec	22,5	Saturated paper wipe	Big
Test 2	Testrun 1	Plastic	B	Coated	Klübertec	15	Saturated paper wipe	Big
	Testrun 2	Plastic	C	Coated	Klübertec	7,5	Saturated paper wipe	Big
	Testrun 3	Plastic	D	Coated	Klübertec	2,5	Saturated paper wipe	Big
	Testrun 4	Plastic	D	Coated	Klübertec	2,5	Saturated paper wipe	Big
	Testrun 5	Plastic	D	Coated	Klübertec	2,5	Saturated paper wipe	Big
	Testrun 6	Plastic	D	Coated	Klübertec	2,5	Saturated paper wipe	Big
Test 3	Testrun 1	Insulation	A	Coated	Klübertec	2,5	Saturated paper wipe	Big
	Testrun 2	Insulation	B	Coated	Klübertec	2,5	Saturated paper wipe	Big
	Testrun 3	Insulation	C	Coated	Klübertec	1	Saturated paper wipe	Big
	Testrun 4	Insulation	D	Coated	Klübertec	1	Saturated paper wipe	Big
Test 4	Testrun 1	Plastic	A	Coated	Klübertec	1	Clean paper wipe	Small
	Testrun 2	Plastic	B	Coated	Klübertec	1	Clean paper wipe	Small
	Testrun 3	Plastic	C	Coated	Klübertec	1	Clean paper wipe	Small
	Testrun 4	Plastic	D	Coated	Klübertec	1	Clean paper wipe	Small
Test 5	Testrun 1	Plastic	A	Coated	Klübertec	1	Clean paper wipe	Small
	Testrun 2	Plastic	B	Coated	Klübertec	1	Clean paper wipe	Small
	Testrun 3	Plastic	C	Coated	Klübertec	0,5	Clean paper wipe	Small
	Testrun 4	Plastic	D	Coated	Klübertec	0,5	Clean paper wipe	Small
	Testrun 5	Plastic	A	Coated	Klübertec	1	Clean paper wipe	Small
	Testrun 6	Plastic	B	Coated	Klübertec	1	Clean paper wipe	Small
	Testrun 7	Plastic	C	Coated	Klübertec	0,5	Clean paper wipe	Small
	Testrun 8	Plastic	D	Coated	Klübertec	0,5	Clean paper wipe	Small
Test 6	Testrun 1	Plastic	A	Coated	Olive	1	Clean paper wipe	Small
	Testrun 2	Plastic	B	Coated	Olive	1	Clean paper wipe	Small
	Testrun 3	Plastic	C	Coated	Olive	1	Clean paper wipe	Small
	Testrun 4	Plastic	D	Coated	Olive	1	Clean paper wipe	Small
	Testrun 5	Plastic	A	Coated	Olive	1,5	Clean paper wipe	Small
	Testrun 6	Plastic	B	Coated	Olive	2	Clean paper wipe	Small
	Testrun 7	Plastic	C	Coated	Olive	2,5	Clean paper wipe	Small
	Testrun 8	Plastic	D	Coated	Olive	3	Clean paper wipe	Small

Table 10: Tape Test Logbook Testrun 1 - 6

		Tape	Plate	Plate type	Oil type	Oil V.	Application method	Sensor
Test 7	Testrun 1	Plastic	A	Coated	Cutting	0,5	Clean paper wipe	Small
	Testrun 2	Plastic	B	Coated	Cutting	1	Clean paper wipe	Small
	Testrun 3	Plastic	C	Coated	Cutting	1,5	Clean paper wipe	Small
	Testrun 4	Plastic	D	Coated	Cutting	2	Clean paper wipe	Small
	Testrun 5	Plastic	A	Coated	WD 40	1	Clean paper wipe	Small
	Testrun 6	Plastic	B	Coated	WD 40	2	Clean paper wipe	Small
	Testrun 7	Plastic	C	Coated	WD 40	2	Clean paper wipe	Small
	Testrun 8	Plastic	D	Coated	WD 40	3	Clean paper wipe	Small
	Testrun 9	Plastic	A	Coated	BioCut	1	Clean paper wipe	Small
	Testrun 10	Plastic	B	Coated	BioCut	2	Clean paper wipe	Small
	Testrun 11	Plastic	C	Coated	Shell	1	Clean paper wipe	Small
	Testrun 12	Plastic	D	Coated	Shell	2	Clean paper wipe	Small
Test 8	Testrun 2	Plastic	A	Coated	Klübertec	2	Clean paper wipe	Small
	Testrun 4	Plastic	B	Coated	Klübertec	2	Clean paper wipe	Small
	Testrun 5	Plastic	E	Steel	Klübertec	2	Clean paper wipe	Small
	Testrun 6	Plastic	F	Steel	Klübertec	2	Clean paper wipe	Small
	Testrun 7	Plastic	A	Coated	BioCut	2	Clean paper wipe	Small
	Testrun 9	Plastic	B	Coated	BioCut	2	Clean paper wipe	Small
	Testrun 10	Plastic	E	Steel	BioCut	2	Clean paper wipe	Small
	Testrun 11	Plastic	F	Steel	BioCut	2	Clean paper wipe	Small
	Testrun 12	Plastic	A	Coated	Shell	2	Clean paper wipe	Small
	Testrun 14	Plastic	B	Coated	Shell	2	Clean paper wipe	Small
	Testrun 15	Plastic	E	Steel	Shell	2	Clean paper wipe	Small
	Testrun 16	Plastic	F	Steel	Shell	2	Clean paper wipe	Small
	Testrun 17	Plastic	A	Coated	Cutting	2	Clean paper wipe	Small
	Testrun 18	Plastic	B	Coated	Cutting	2	Clean paper wipe	Small
	Testrun 19	Plastic	E	Steel	Cutting	2	Clean paper wipe	Small
	Testrun 20	Plastic	F	Steel	Cutting	2	Clean paper wipe	Small
	Testrun 21	Plastic	A	Coated	WD 40	2	Clean paper wipe	Small
	Testrun 22	Plastic	B	Coated	WD 40	2	Clean paper wipe	Small
	Testrun 23	Plastic	E	Steel	WD 40	2	Clean paper wipe	Small
	Testrun 24	Plastic	F	Steel	WD 40	2	Clean paper wipe	Small
	Testrun 25	Plastic	A	Coated	Olive	2	Clean paper wipe	Small
	Testrun 26	Plastic	B	Coated	Olive	2	Clean paper wipe	Small
	Testrun 27	Plastic	E	Steel	Olive	2	Clean paper wipe	Small
	Testrun 28	Plastic	F	Steel	Olive	2	Clean paper wipe	Small
	Testrun 29	Plastic	A	Coated		0	Clean	Small
	Testrun 30	Plastic	B	Coated		0	Clean	Small
	Testrun 31	Plastic	E	Steel		0	Clean	Small
	Testrun 32	Plastic	F	Steel		0	Clean	Small

Table 11: Tape Test Logbook Testrun 7 - 8

		Tape	Plate	Plate type	Oil type	Oil V.	Application method	Sensor
Test 9	Testrun 1	Insulation	A	Coated	Klübertec	2	Clean paper wipe	Small
	Testrun 2	Insulation	B	Coated	Klübertec	2	Clean paper wipe	Small
	Testrun 3	Insulation	E	Steel	Klübertec	2	Clean paper wipe	Small
	Testrun 4	Insulation	F	Steel	Klübertec	2	Clean paper wipe	Small
	Testrun 5	Insulation	A	Coated	BioCut	2	Clean paper wipe	Small
	Testrun 6	Insulation	B	Coated	BioCut	2	Clean paper wipe	Small
	Testrun 7	Insulation	E	Steel	BioCut	2	Clean paper wipe	Small
	Testrun 8	Insulation	F	Steel	BioCut	2	Clean paper wipe	Small
	Testrun 9	Insulation	A	Coated	Shell	2	Clean paper wipe	Small
	Testrun 10	Insulation	B	Coated	Shell	2	Clean paper wipe	Small
	Testrun 11	Insulation	E	Steel	Shell	2	Clean paper wipe	Small
	Testrun 12	Insulation	F	Steel	Shell	2	Clean paper wipe	Small
	Testrun 13	Insulation	A	Coated		0	Clean	Small
	Testrun 14	Insulation	B	Coated		0	Clean	Small
	Testrun 15	Insulation	E	Steel		0	Clean	Small
	Testrun 16	Insulation	F	Steel		0	Clean	Small

Table 12: Tape Test Logbook Testrun 9