Introduction to Non-Destructive Testing of Composite Materials

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YOUR HOSTS

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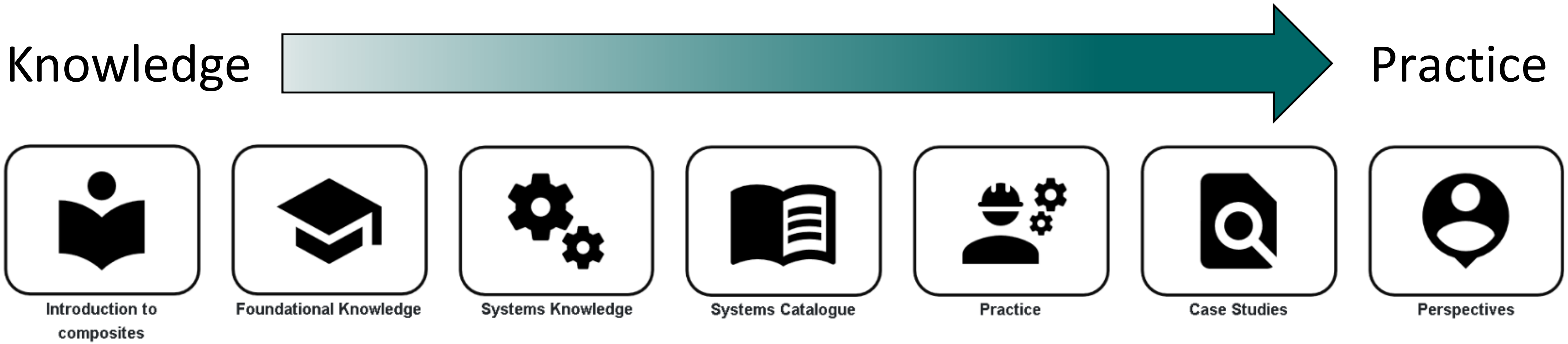
- Ba. and M.Sc. in Aerospace Engineering
- 6 years experience in industry working as Project Manager and NDT Engineer on polymer matrix composites in aerospace, automotive, racing and marine.

KNOWLEDGE IN PRACTICE CENTRE (KPC)

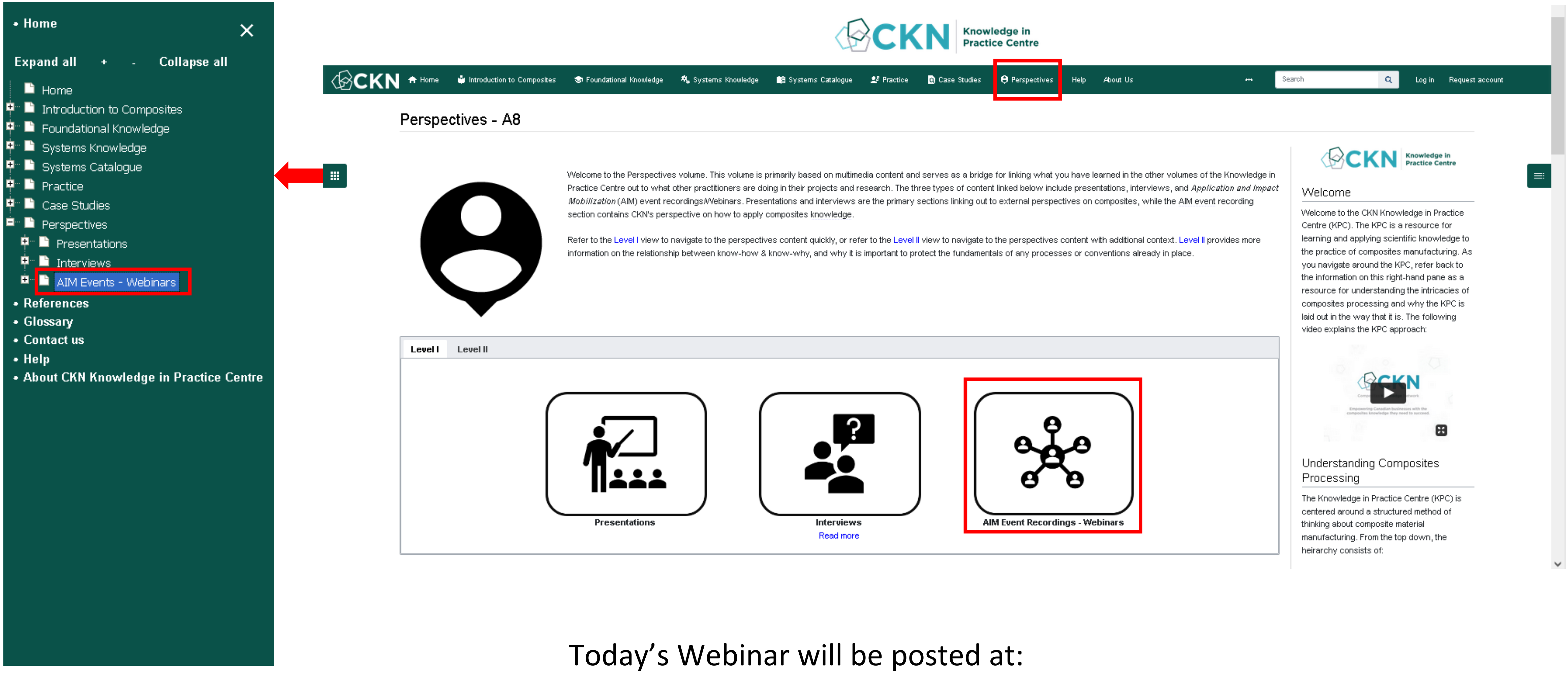
- A freely available online resource for composite materials engineering:

  compositeskn.org/KPC

- Focus on practice, guided by foundational knowledge and a systems-based approach to thinking about composites manufacturing



PAST WEBINAR RECORDINGS AVAILABLE



Today's Webinar will be posted at:
https://compositeskn.org/KPC/A366

TODAY'S TOPIC:

Introduction to Non-Destructive Testing of Composite Materials

OUTLINE

- Defects in composites
- NDT methods
- Case Studies

EXAMPLE: NDT FOR AEROSPACE

In Aerospace, safety is the most critical aspect. To address this point, many techniques have been developed to inspect aircrafts and satellites structures.

When NDT are needed?

- Development phase
- Product lifecycle
- Testing and certification to test performance and durability and investigate issues
- Maintenance: NDT to inspect in-service aircraft for damage and cracks at regular intervals to guarantee airworthiness and safety

DETECTABLE DEFECTS

- **Common Defects on Composites**
  - Cracks
  - Fiber breakage
  - Air voids
  - Porosity
  - Excesses of resin
  - Delaminations
  - Disbondings
  - Wrinkles
  - Foreign materials in the laminate

- **Common Defects on Metals**
  - Air voids
  - Cracks
  - Environmental Damage (Corrosion…)
  - Bad welding

	VT	PT	RX	PM	UT	IRT	ET	AT
Metals	•	•	•	•	•	•	•	•
Composites	•		•		•	•		•
Air Voids			✓	✓	✓			
Homogeneity of the material			✓		✓		✓	
Delaminations			✓	✓	✓			
Bonding	✓				✓	✓		
Cracks	✓	✓	✓	✓	✓	✓	✓	✓
Inclusions			✓	✓	✓			

EXAMPLE: SATELLITE STRUCTURE INSPECTION

MANUFACTURING VS IN-SERVICE DEFECTS

- **Common Defects during Manufacturing process**
  - Air voids
  - Porosity
  - Excess of resin
  - Disbondings
  - Wrinkles
  - Foreign materials in the laminate

- **Common Defects during component Life-Cycle**
  - Matrix Cracks/Fiber Breakage
  - Delamination
  - Disbonding

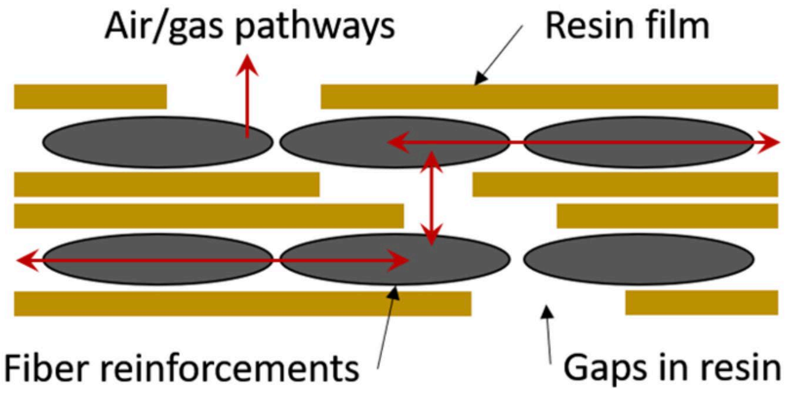
AIR VOIDS AND POROSITY

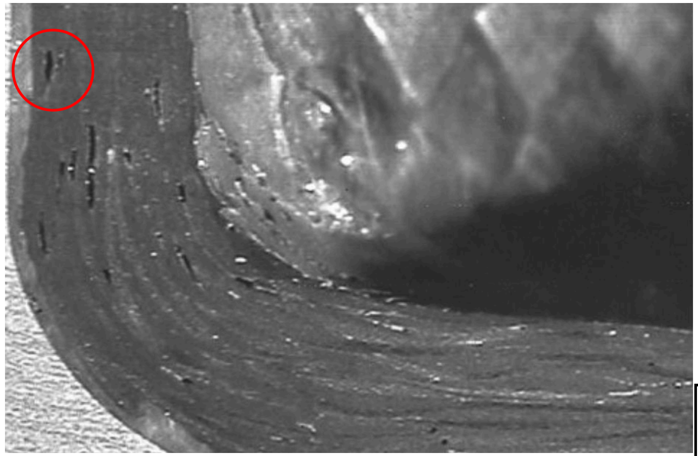
Air Voids

- Air voids refer to pockets or gaps of air trapped within a composite material.
- Air voids can be introduced during the manufacturing process of composite materials.
- The presence of air voids can weaken the material, reduce its structural integrity, and decrease its overall mechanical properties such as strength, stiffness, and durability.
- Minimizing air voids is important to ensure the composite material's performance meets the desired specifications.

Porosity

- Porosity is a measure of the overall void content within a composite material.
- Porosity includes not only air voids but also other types of voids, such as resin-rich or resin-poor regions within the material.
- Is typically expressed as a percentage and is calculated by dividing the total volume of voids by the total volume of the composite laminate.
- High porosity levels can negatively impact the material's mechanical properties, making it less reliable and durable.

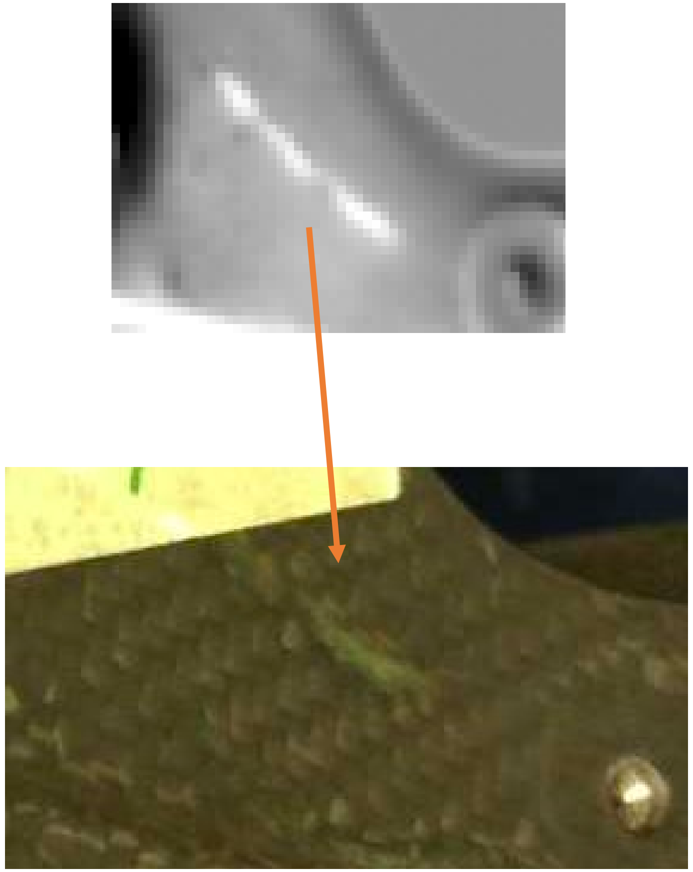




LOCALIZED EXCESS OF RESIN

A localized excess of resin defect in composite materials refers to a specific region or area within the composite laminate where there is an excessive amount of resin compared to the surrounding material.

- The localized excess of resin can be caused by various factors during the manufacturing process. It may result from uneven application of resin, improper consolidation or compression, vacuum bagging issues, or resin pooling in certain areas.
- This defect can lead to reduced mechanical properties, weight increase, reduced fiber content and cosmetic issues (carbon look parts).
- To prevent localized excess resin defects, manufacturers often focus on optimizing the resin application and consolidation processes. Proper vacuum bagging techniques, pressure control, and tooling design can help distribute resin more evenly. In some cases, repairs may be possible.



DISBONDING OR DELAMINATION

Disbonding in composite materials refers to the separation or delamination of the layers or plies within a composite structure or between the laminate and metal parts in the structure.

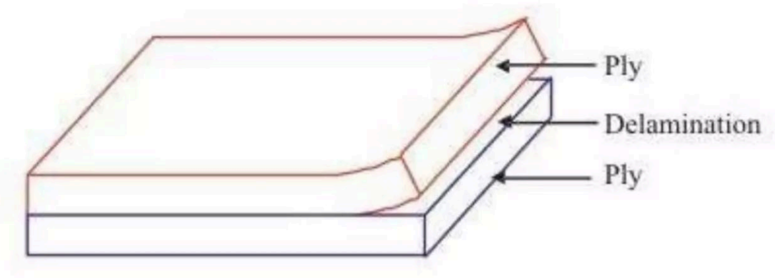
CAUSES

- Inadequate Bonding: this can result from factors such as improper surface preparation, contamination, or curing issues.
- Impact or Mechanical Stress: External forces, impacts and regions where stress concentrations are high.
- Environmental Factors: Exposure to environmental conditions, such as moisture, temperature variations, or chemical exposure.

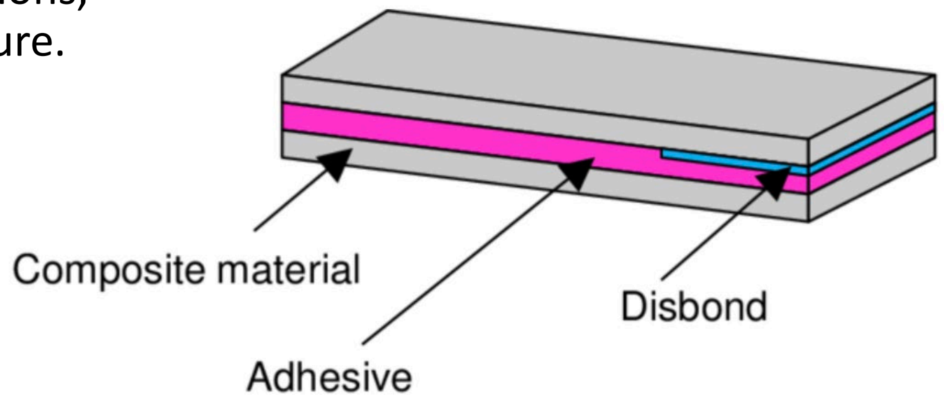
EFFECTS

1. Reduced Structural Integrity
2. Reduced Mechanical Properties
3. Cosmetic Issues

Delamination

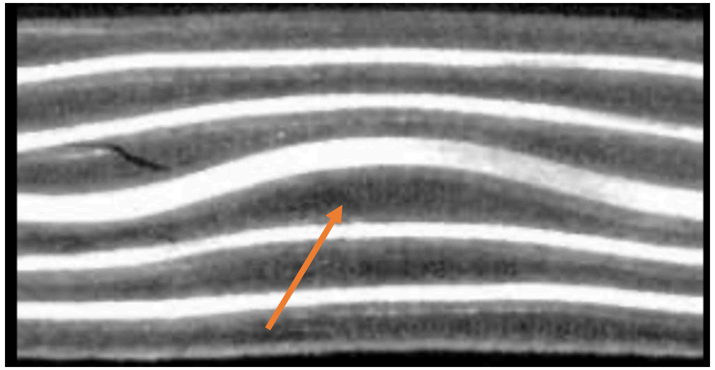


Disbonding



WRINKLES

Wrinkles in composite materials refer to undesirable, irregular, and often visible surface deformations that resemble creases or folds. These wrinkles can occur during the manufacturing, curing, or post-processing of composite components. Wrinkles are a cosmetic defect and can also have implications for the structural integrity of the composite.



CAUSES

- Improper Lay-up: Wrinkles can result from the improper placement of composite layers or plies during the lay-up process.
- Resin Flow: Insufficient or uneven resin flow during the curing process can cause wrinkles.
- Vacuum Bagging Issues: Improper vacuum pressure, leaks, or sealing problems can lead to uneven pressure distribution.
- Temperature and Curing Issues: Variations in temperature or improper curing conditions can affect the viscosity and flow of the resin.

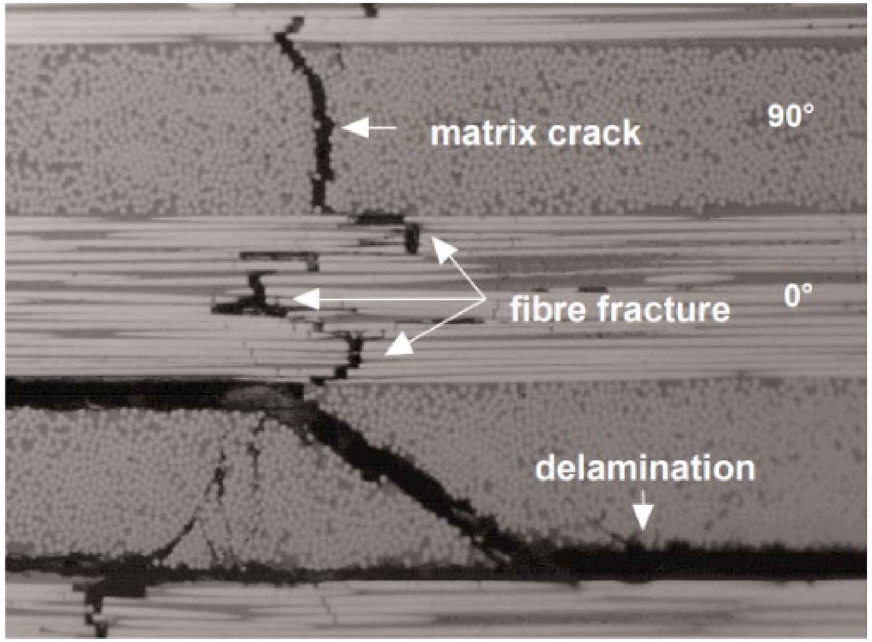
EFFECTS

1. Cosmetic Imperfections.
2. Reduced Structural Integrity.

MATRIX CRACK

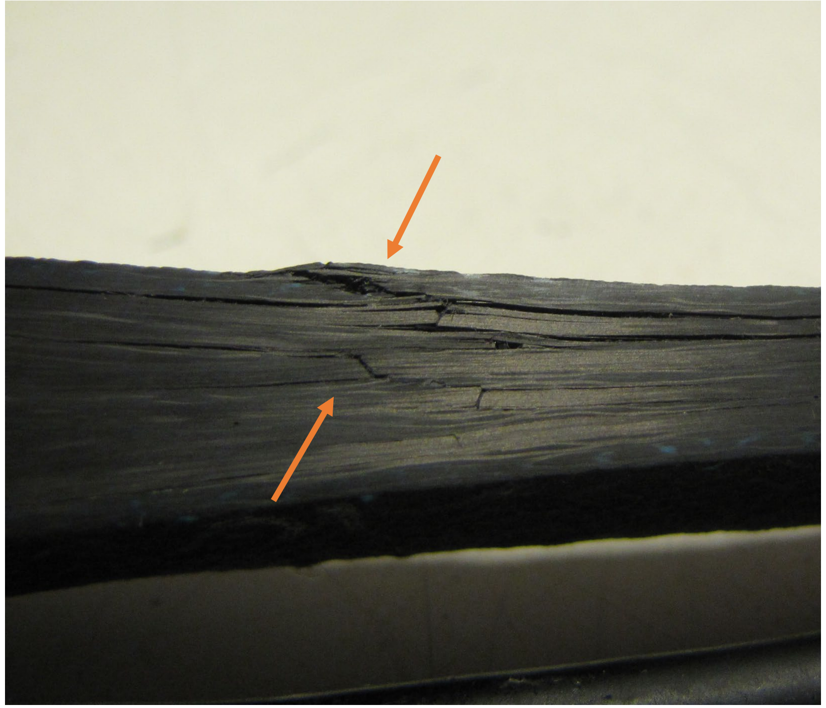
Matrix cracks are cracks or fractures that occur within the matrix material of a composite, which surrounds and binds the reinforcing fibers (e.g., carbon, glass, aramid).

- **Causes**: Matrix cracks can develop due to various factors, such as tensile, compressive, or shear loads that exceed the matrix's strength, impact or fatigue loading, thermal stresses, or manufacturing defects.
- **Effects**: Matrix cracks typically weaken the composite's load-carrying capacity, especially in the direction parallel to the fibers. These cracks can propagate through the matrix and may eventually lead to delamination or fiber debonding. They reduce the composite's stiffness and contribute to the initiation of other damage mechanisms.
- **Detection**: Matrix cracks may be detected using non-destructive testing (NDT) methods like ultrasonic inspection or X-ray imaging. Visual inspection may also reveal cracks on the surface, though internal cracks can be more challenging to identify.



FIBER BREAKAGE

Fiber breakage refers to the rupture or fracture of the reinforcing fibers in a composite material.



- **Causes**: Fiber breakage can occur when the applied loads exceed the tensile strength of the fibers, often due to excessive stress concentrations, impact loads, or repeated cyclic loading. Manufacturing defects, such as fiber misalignment, can also contribute to fiber breakage.
- **Effects**: Fiber breakage significantly reduces the composite's strength, as the fibers are the primary load-carrying component. In addition to strength reduction, fiber breakage can lead to delamination, matrix cracks, and a decrease in stiffness.
- **Detection**: Fiber breakage can be challenging to detect visually unless it has caused visible surface damage. NDT techniques like ultrasonic testing and X-ray inspection are often used to assess the extent of fiber breakage.

NDT METHODS USED FOR COMPOSITES

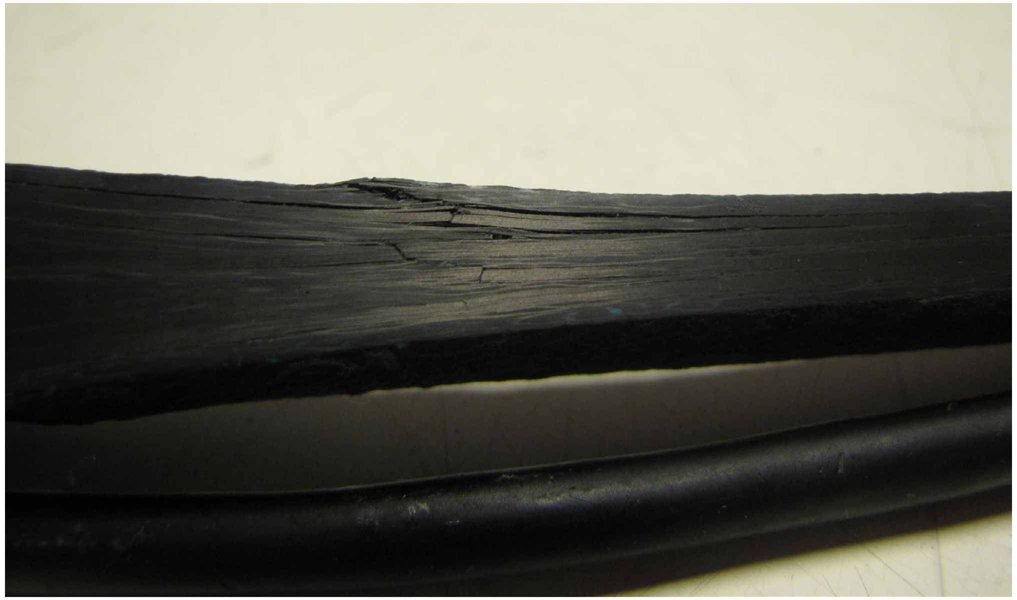
- **Common NDT tests on Composites**
  - Visual Test (VT)
  - Penetrant Liquid (PT)
  - Acoustic Emission (AT)
  - Ultrasonic Test (UT)
  - Infrared Thermography (IT)
  - X-Ray
  - Computed Tomography (CT)

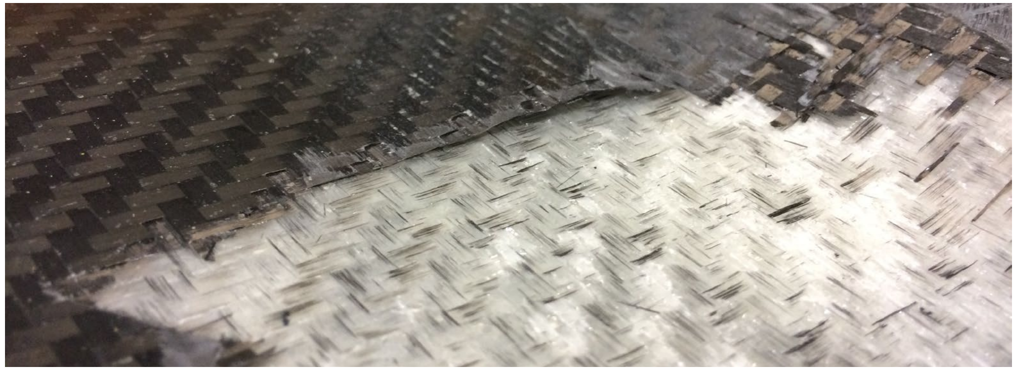
Most Common NDT Methods

VISUAL TEST (VT)

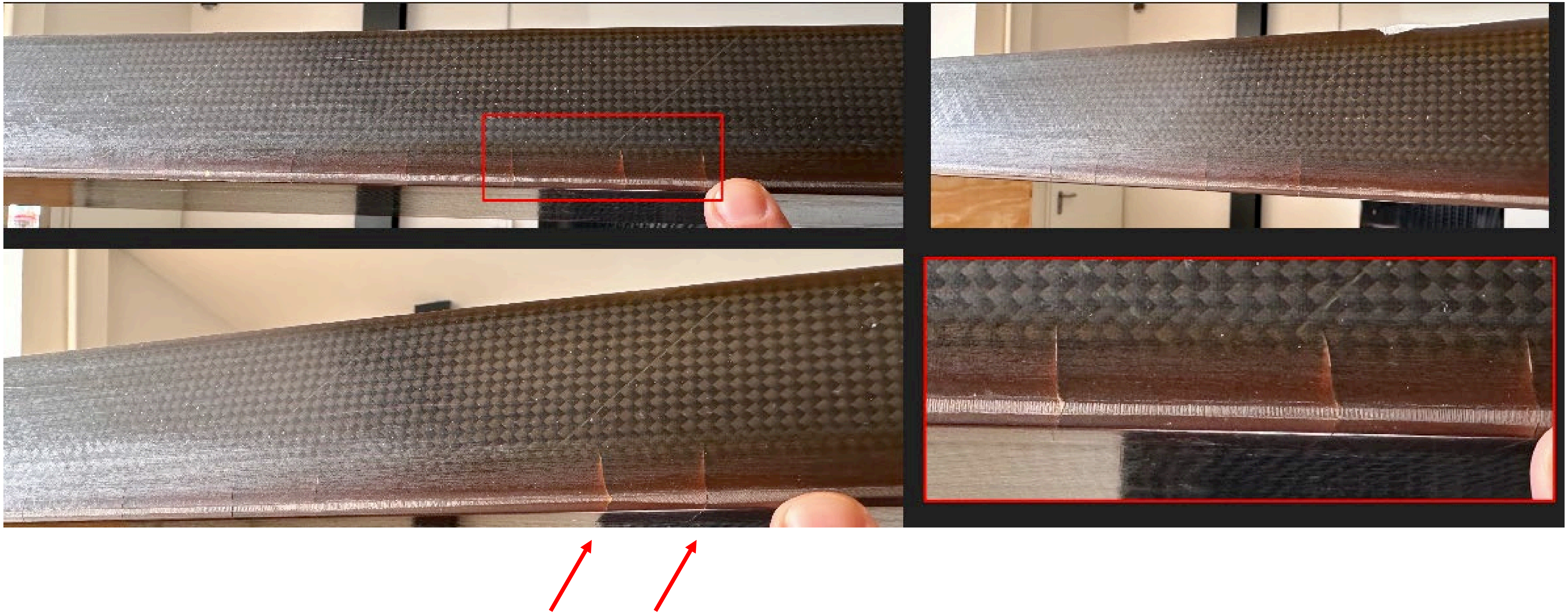
VT uses reflected or transmitted light from test object that is imaged with the human eye or other light-sensing device. The most used techniques that are based on the reflection of a light wave are:

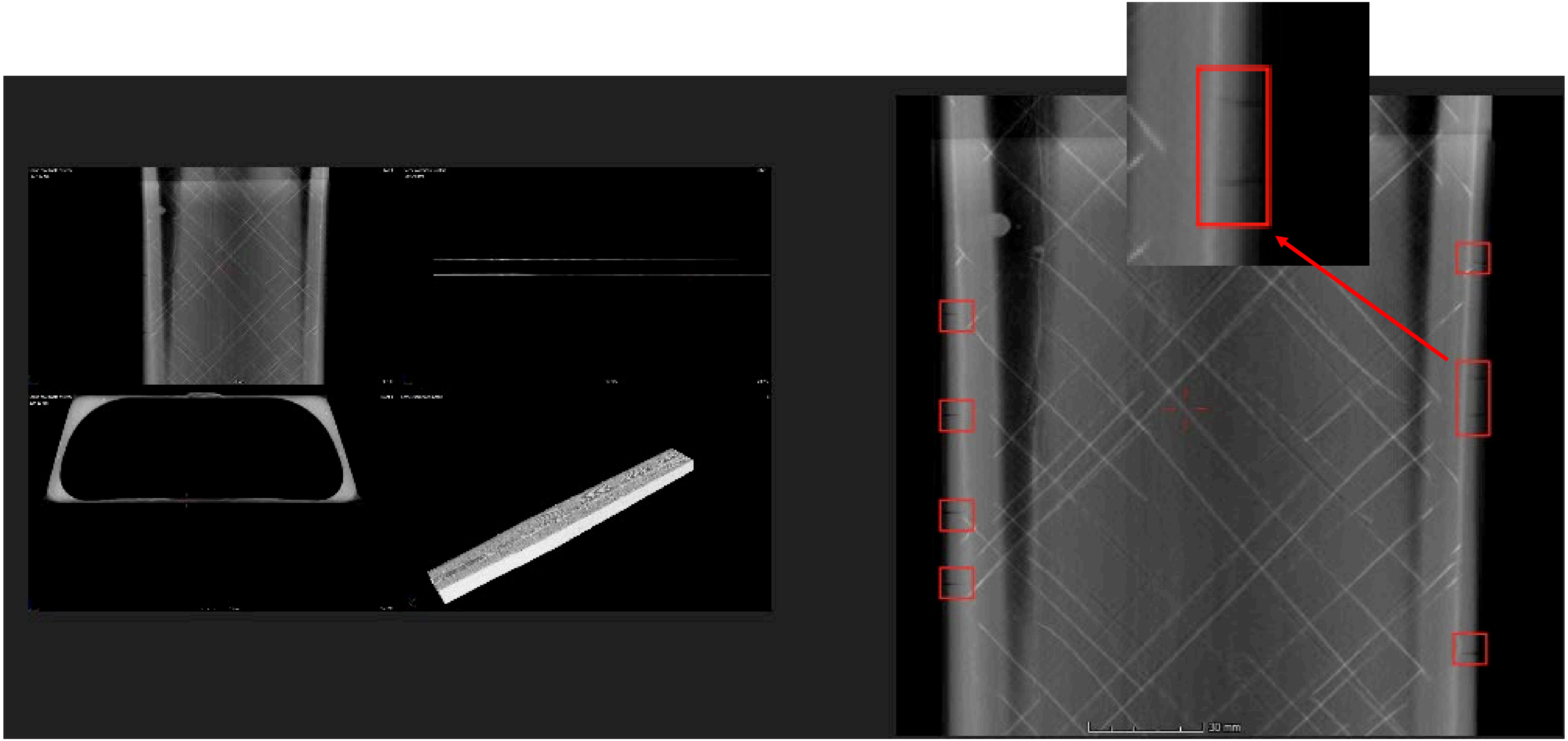
- Naked eye: is capable to detect the width of 1,5-2 mm.
- Focal lens: with the use of a lens it is possible to reach resolution of 0,5mm approximatively.
- Laser scan: a concentrated array of light scan the surface and the superficial defects are detected because they cause a variation in the lighting intensity reflected by the scanned component.
- Holographic methods: these techniques use the properties of optic reflection of the material (most used in the metal components).





EXAMPLE: EXCESS RESIN AND RESIN CRACKS DETECTED WITH VT




30 mm

TAP TEST

Tap testing involves tapping or striking a material with a tool and analyzing the resulting sound or vibration.

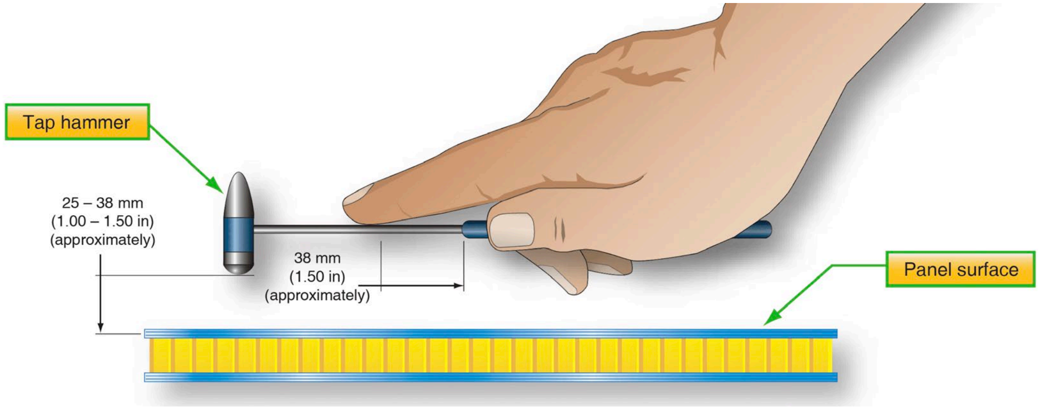
This method is particularly useful for detecting delaminations, voids, or other structural issues in composite materials without causing damage.

Tap Source: Use a tool to gently tap (e.g. hammer) the surface of the composite material.

Listening/Analysis: Listen to the sound produced by the tap or use sensors to measure the resulting vibrations. Changes in the sound or vibration pattern can indicate variations in the material's properties.

Interpretation: A change in the sound or vibration pattern might indicate the presence of a defect like delamination.

Calibration: It's essential to calibrate the testing equipment on known good samples.



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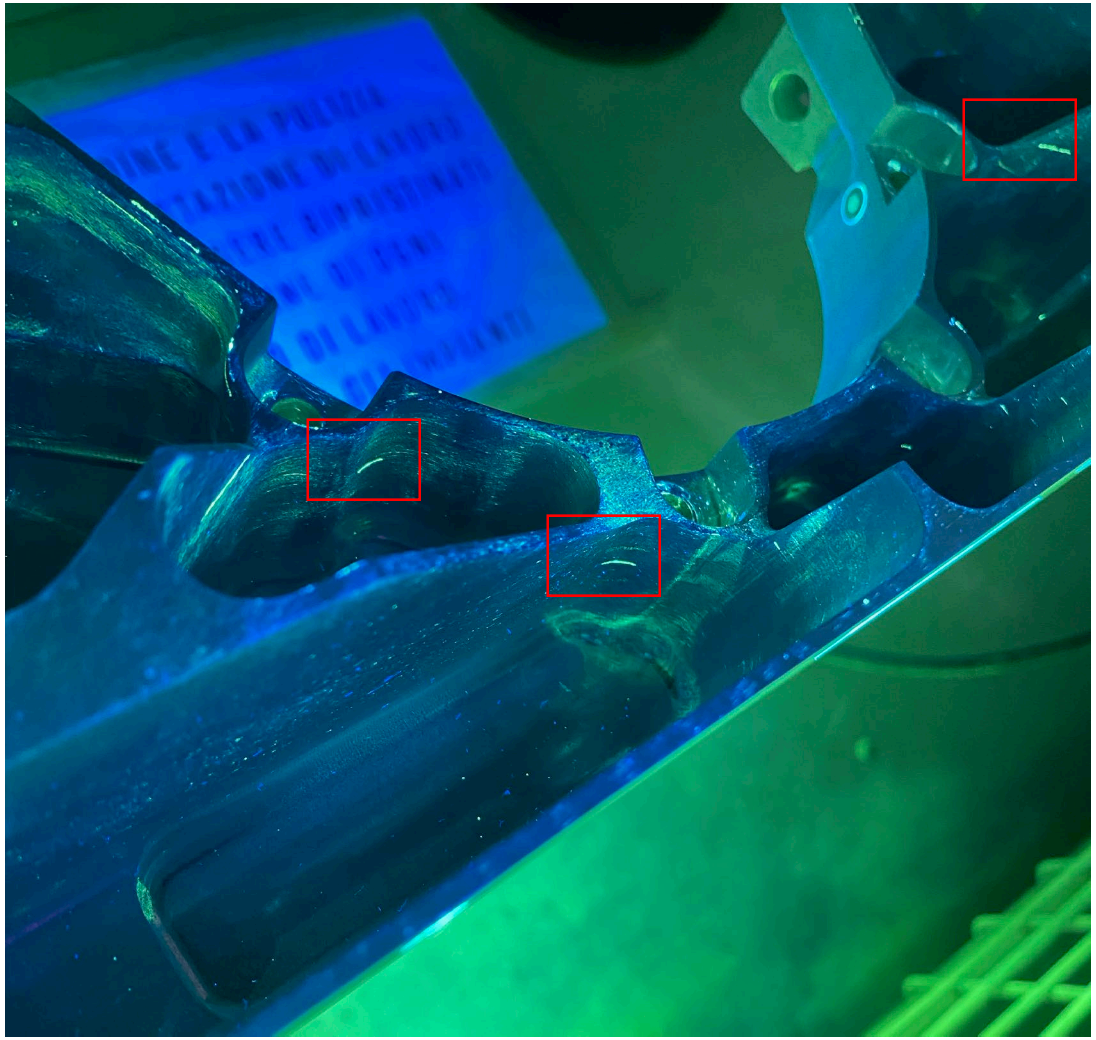
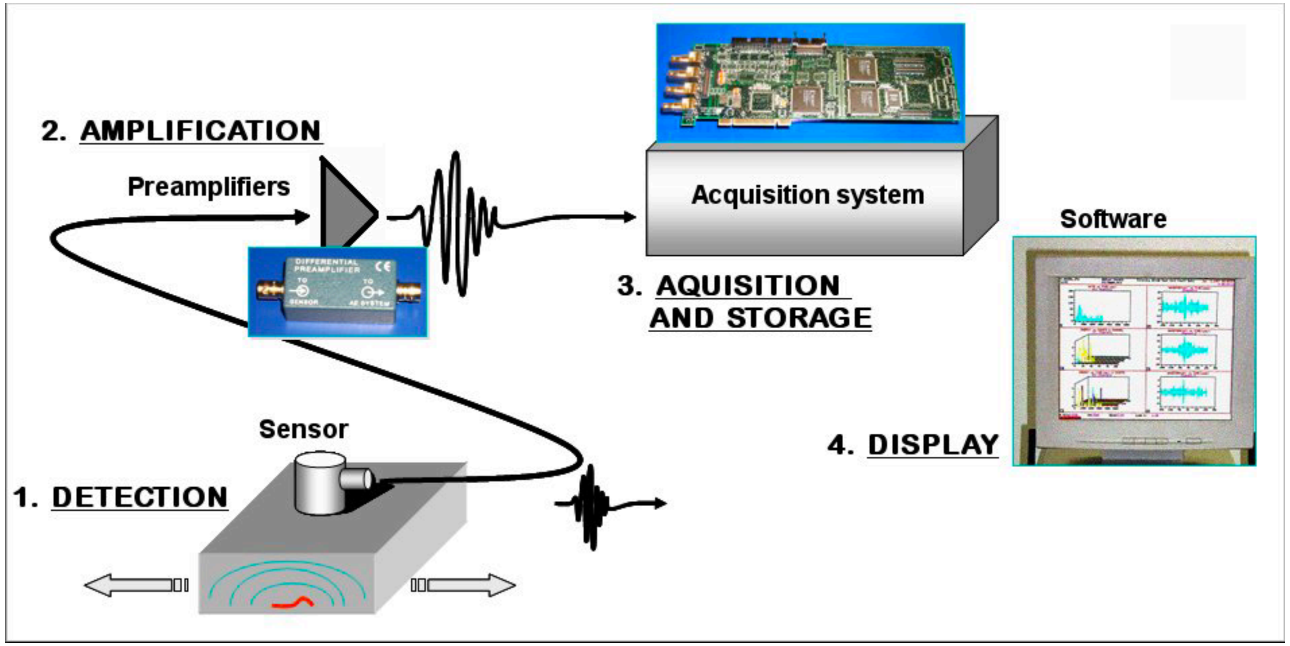
PENETRANT LIQUID (PT)

- It is a surface method that increase the resolution of the human eye inspection emphasizing the difference between defect and component.
- A liquid containing visible or fluorescent dye is applied to surface and enters discontinuities by capillary action.
- It can be applied to any solid non-absorbent material having uncoated surfaces that are not contaminated.
- It is a very easy and inexpensive method, as well as extremely sensitive, very versatile, and require minimal training.
- Capable to detect only discontinuities that are open on the surface and the surface condition must be relatively smooth and free of contaminants.



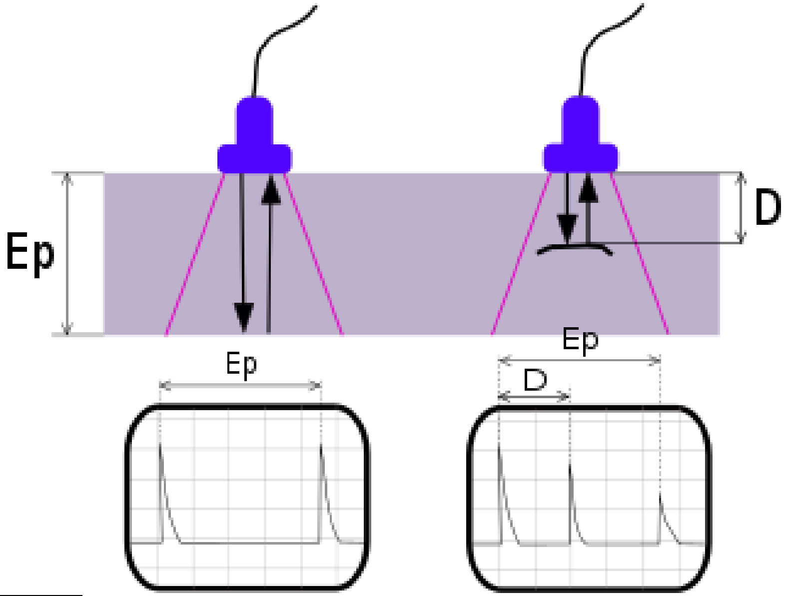
ACOUSTIC EMISSION TEST (AT)

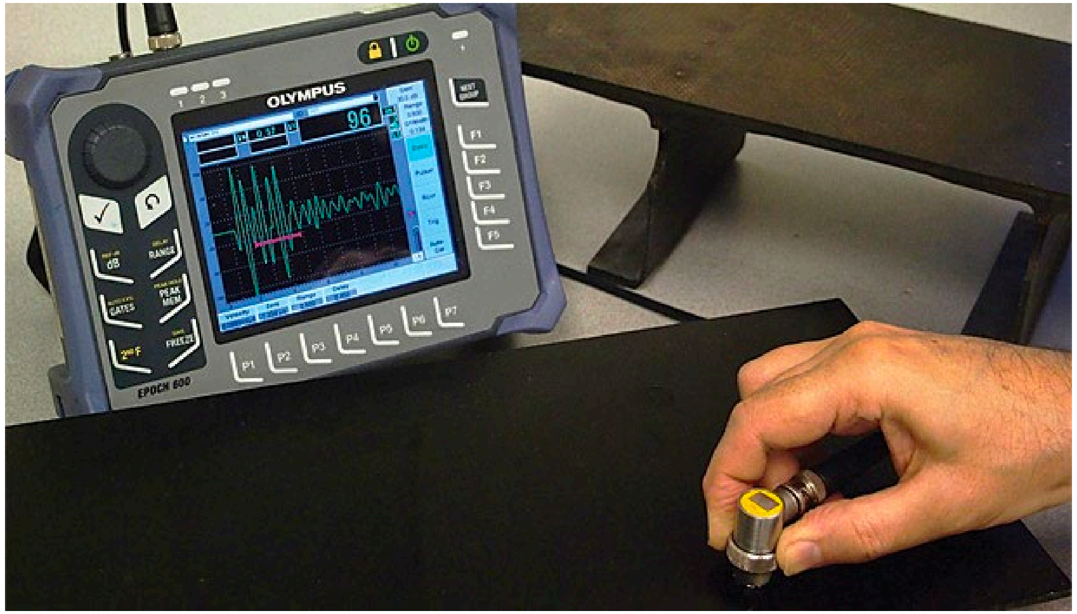
AT tests are volumetric methods capable to detect acoustic or ultrasonic signals from a deformation or degradation of the material. If a load is applied to a specimen this will deform and start storing energy; if a crack start, part of the stored energy will be released. A part of it is absorbed as energy required to amplify the cracked surface, and the remaining sored energy will produce an acoustic activity under the stress waves form. These waves travel from the crack origin until the external surface of the specimen, both directly and as reflected. A sensor detect these low intensity events, that, amplified, are visible on a screen. As seen, this technique is sensible to the mechanic characteristics of the materials.



ULTRASONIC TESTING (UT)

Is a volumetric method and is one of the most used. This method is capable to detect surface and sub-surface discontinuities as well as on thick materials. The technique is based on the ultrasound emission (high-frequency sound pulse) by a probe. The waves are reflected by the different surfaces inside the material. The reflected signals are picked up by the probe and then processed and shown on a screen. Most common frequencies used are between 0.5 to 25 MHz. The data can be represented in three different views: A-scan, S-scan, C-scan. It provides precise high-sensitive results in a very quickly manner. Usually displays thickness information, depth and dimensions of the flaw. Limitations are shown with irregular surfaces, since the signal does not return exactly vertical to the probe but slightly distorted.





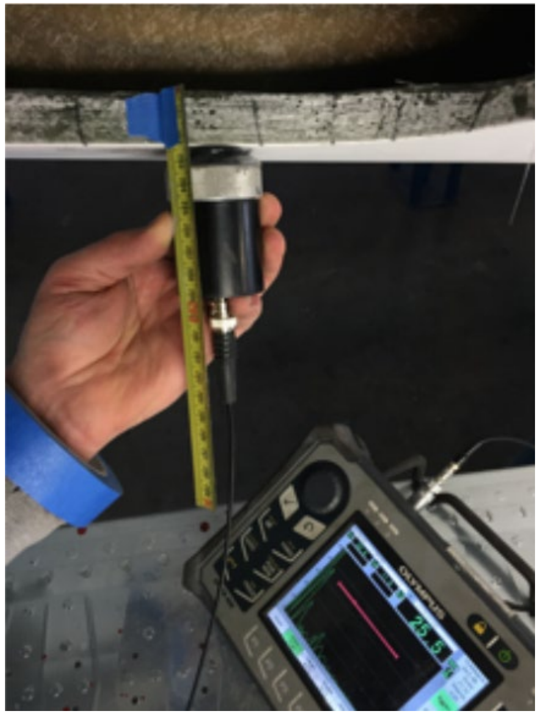
ULTRASONIC TESTING (UT)

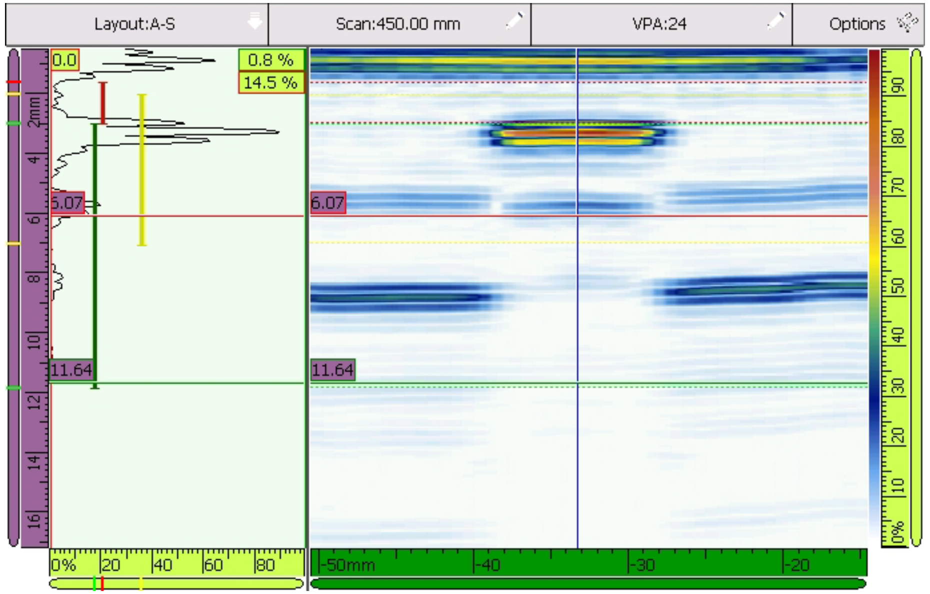
Pros:

- Real time
- High penetration capabilities
- Good detectability for at least most of the kind of discontinuities

Cons:

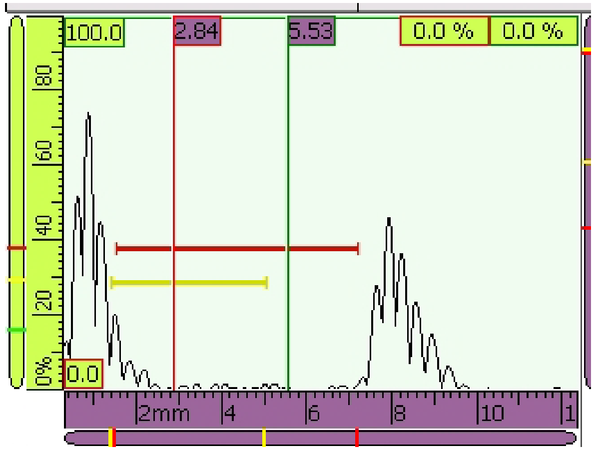
- Not contactless
- Really good only for flat parts



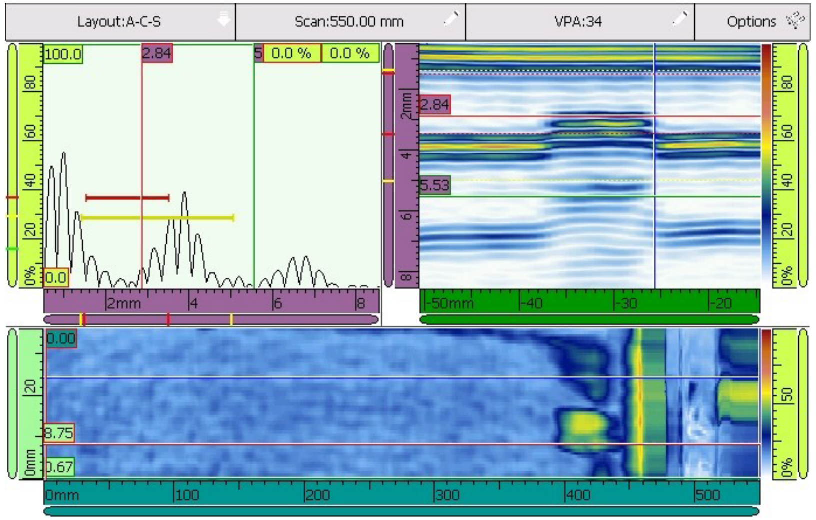


ULTRASONIC TESTING (UT)

UT-PE

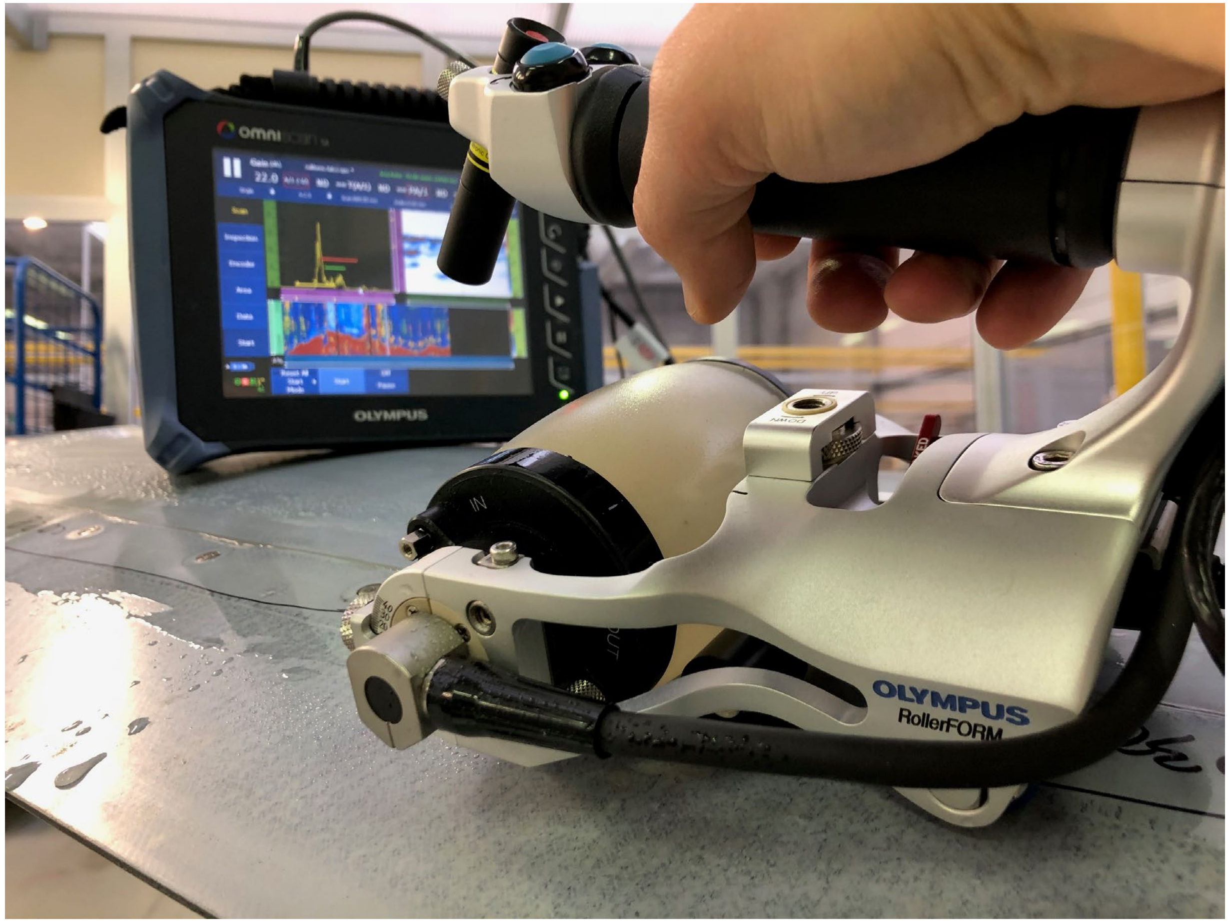


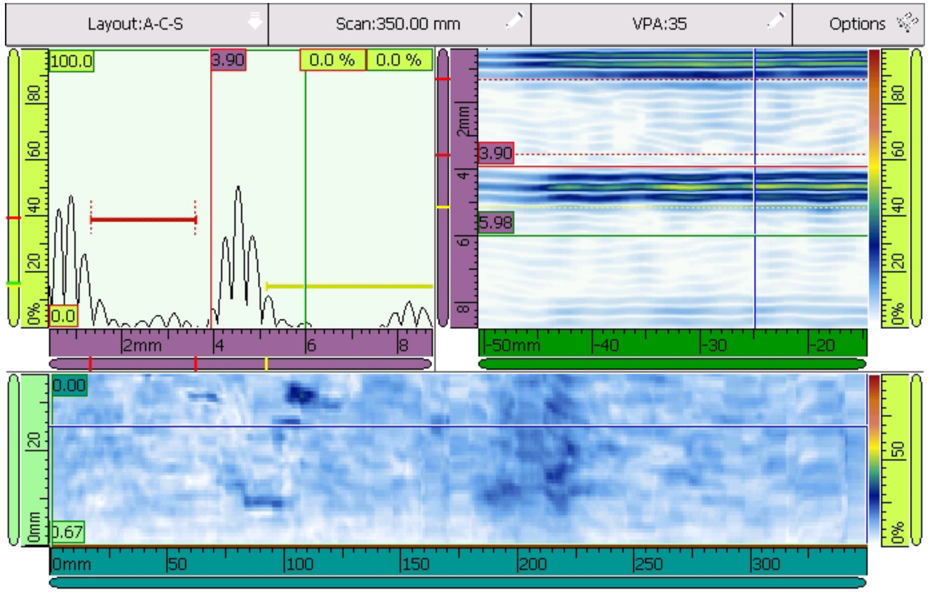
UT-PA



ULTRASONIC TESTING (UT)

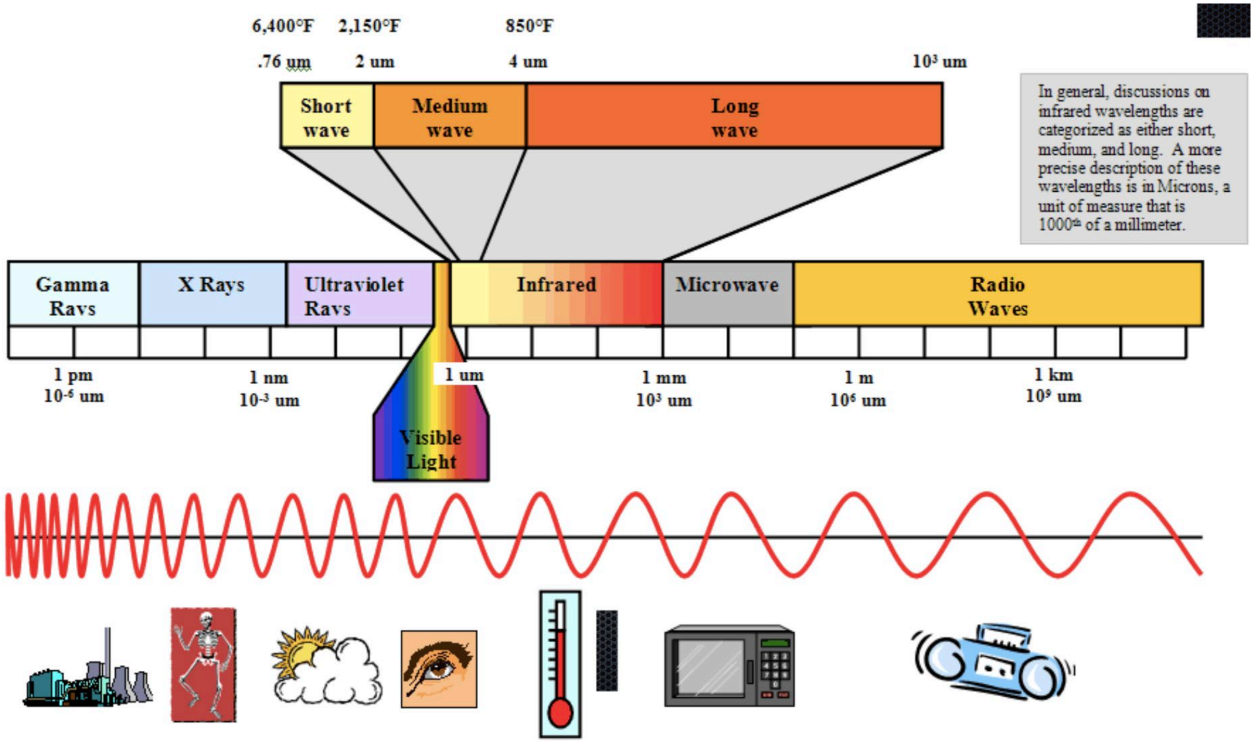
Roller Probe

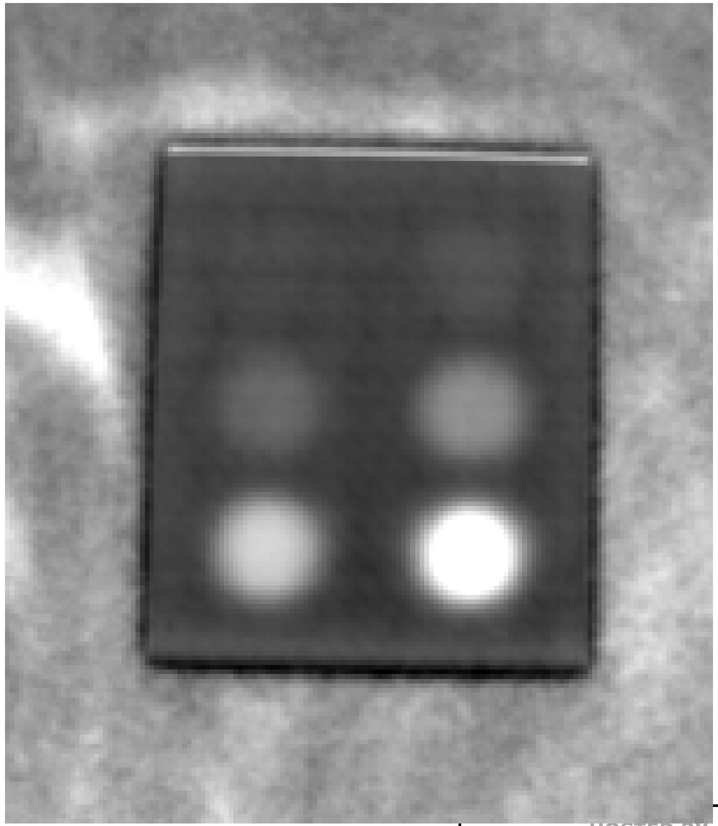




INFRARED THERMOGRAPHY (IRT)

It is a sub-surface method based on the acquisition of thermal images in the IR field. The thermal-camera is capable to detect the temperature of the components that are analyzed measuring the intensity of radiation that comes from the part, and so is capable to detect thermal discontinuities caused bay the presence of defects inside the material. It is used to detect air voids, delamination, disbonding, foreign materials.





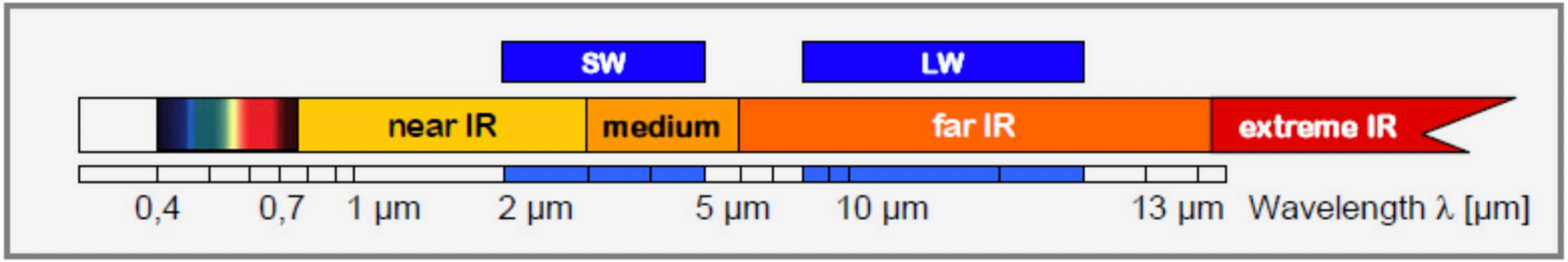
INFRARED THERMOGRAPHY (IRT)

The infrared band is often divided into four smaller ones.

The bands include:

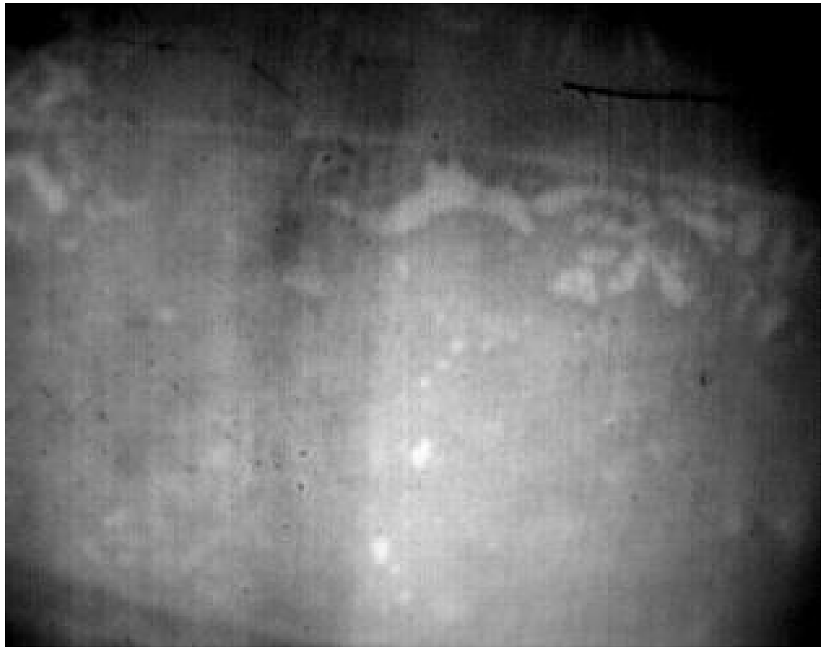
- NEAR IR: 0.78 ÷ 3 µm
- MEDIUM IR: 3 ÷ 6 µm
- FAR IR: 6 ÷ 15 µm
- EXTREME IR: 15 ÷ 1000 µm

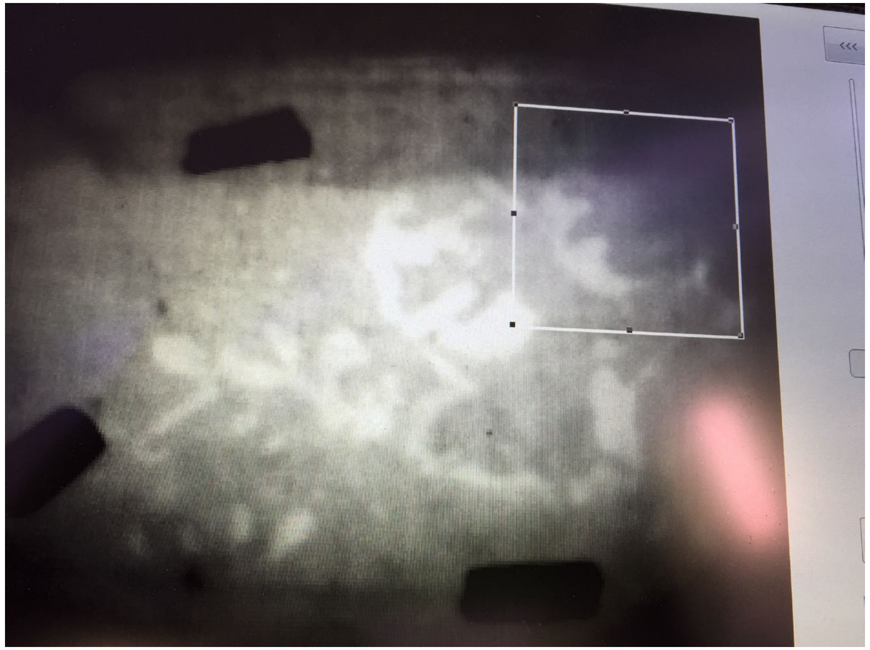
Thermal Spectral Range	Longwave infrared; 8 µm – 14 µm
Thermal Sensitivity	<20 mK (Industrial); <30 mK (Professional)



INFRARED THERMOGRAPHY (IRT)

Defects areas appear as variations in the surface temperature viewed by the infrared camera. These temperature variations are mapped to color or grey-scale pallets for presentation.





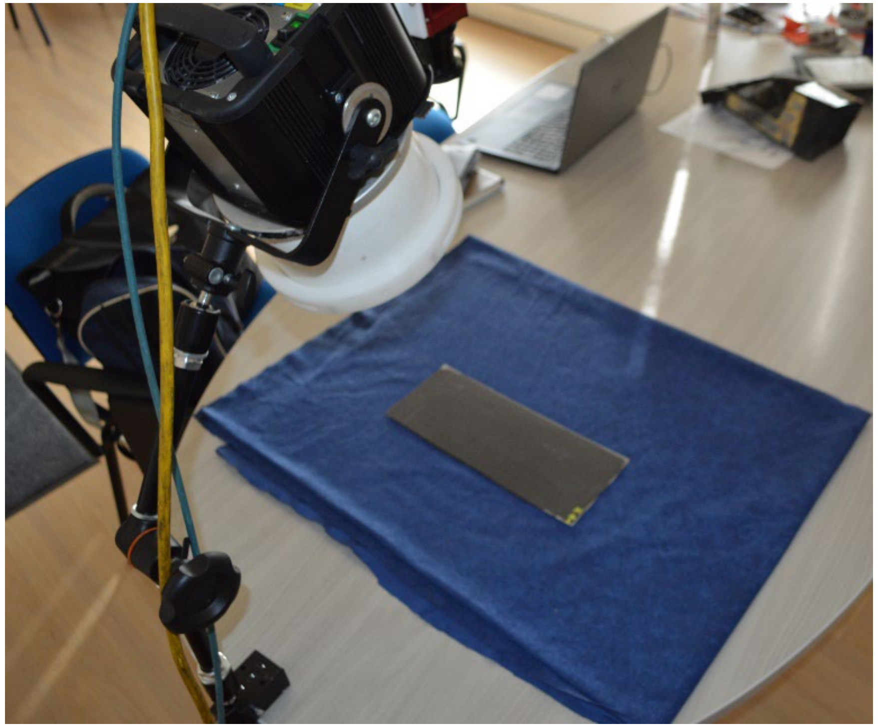
INFRARED THERMOGRAPHY (IRT)

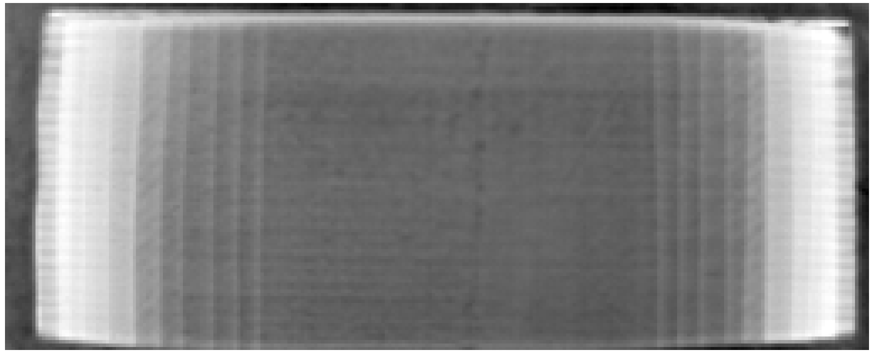
Pros:

- Contactless
- Fast
- Portable
- 2D
- Real time
- Non-invasive
- Not dangerous for human

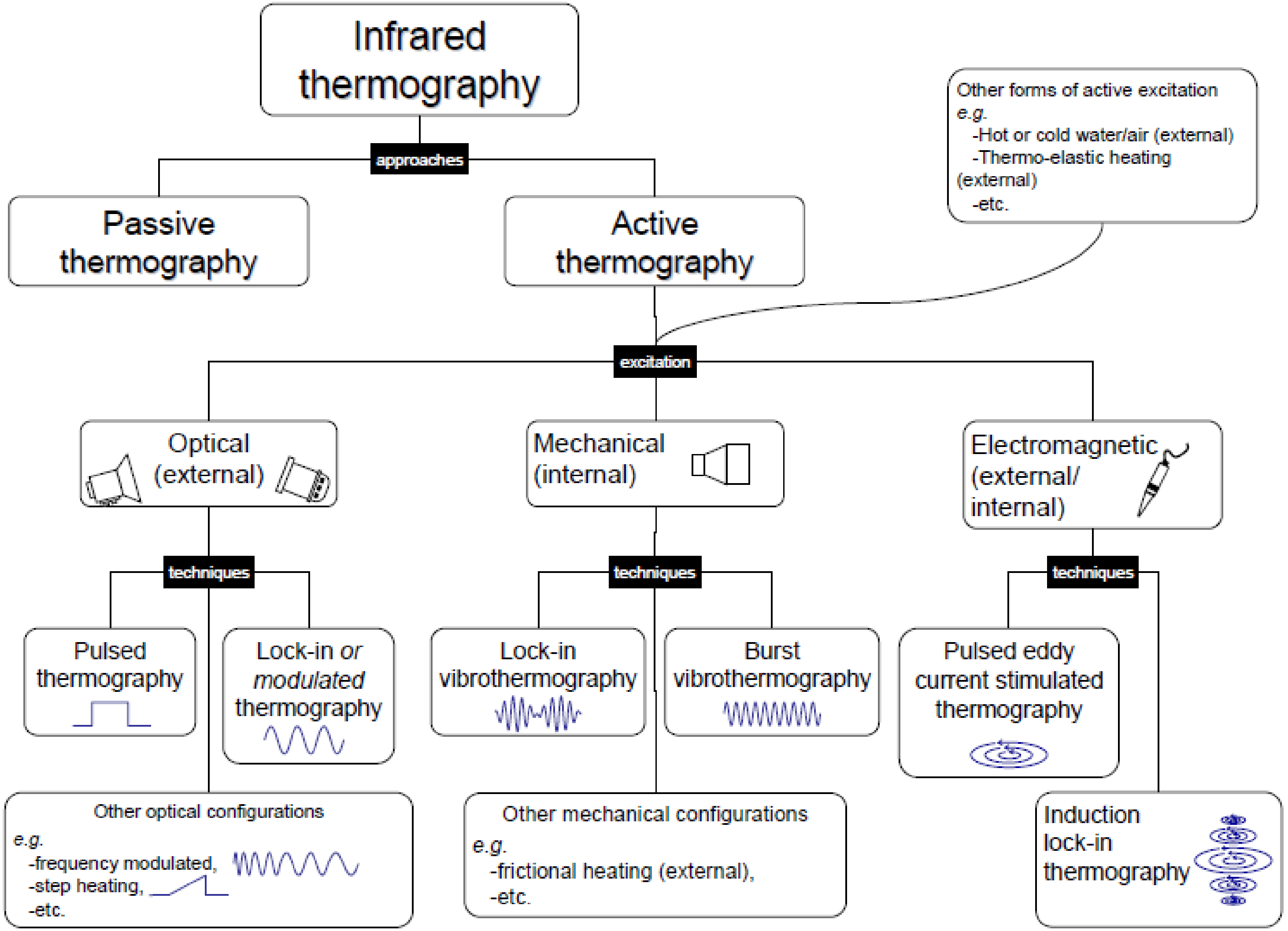
Cons:

- Expensive
- It depends on working conditions
- Good only for thin thicknesses





INFRARED THERMOGRAPHY (IRT)



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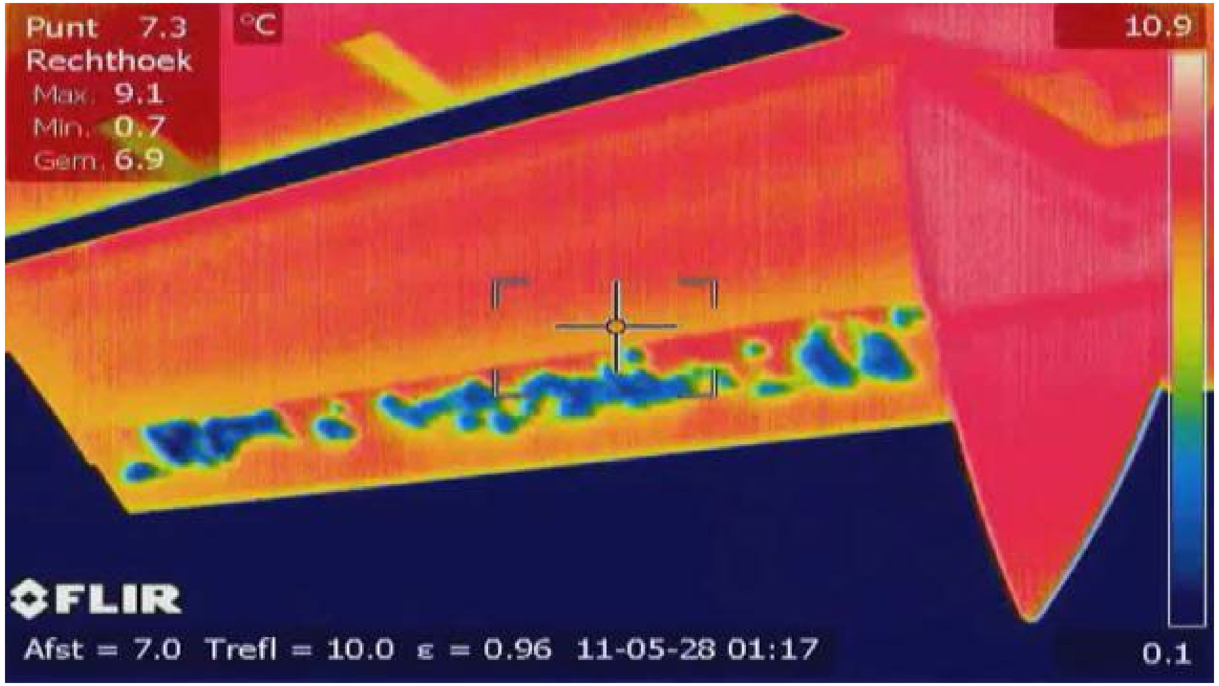
INFRARED THERMOGRAPHY (IRT)

Passive Thermography

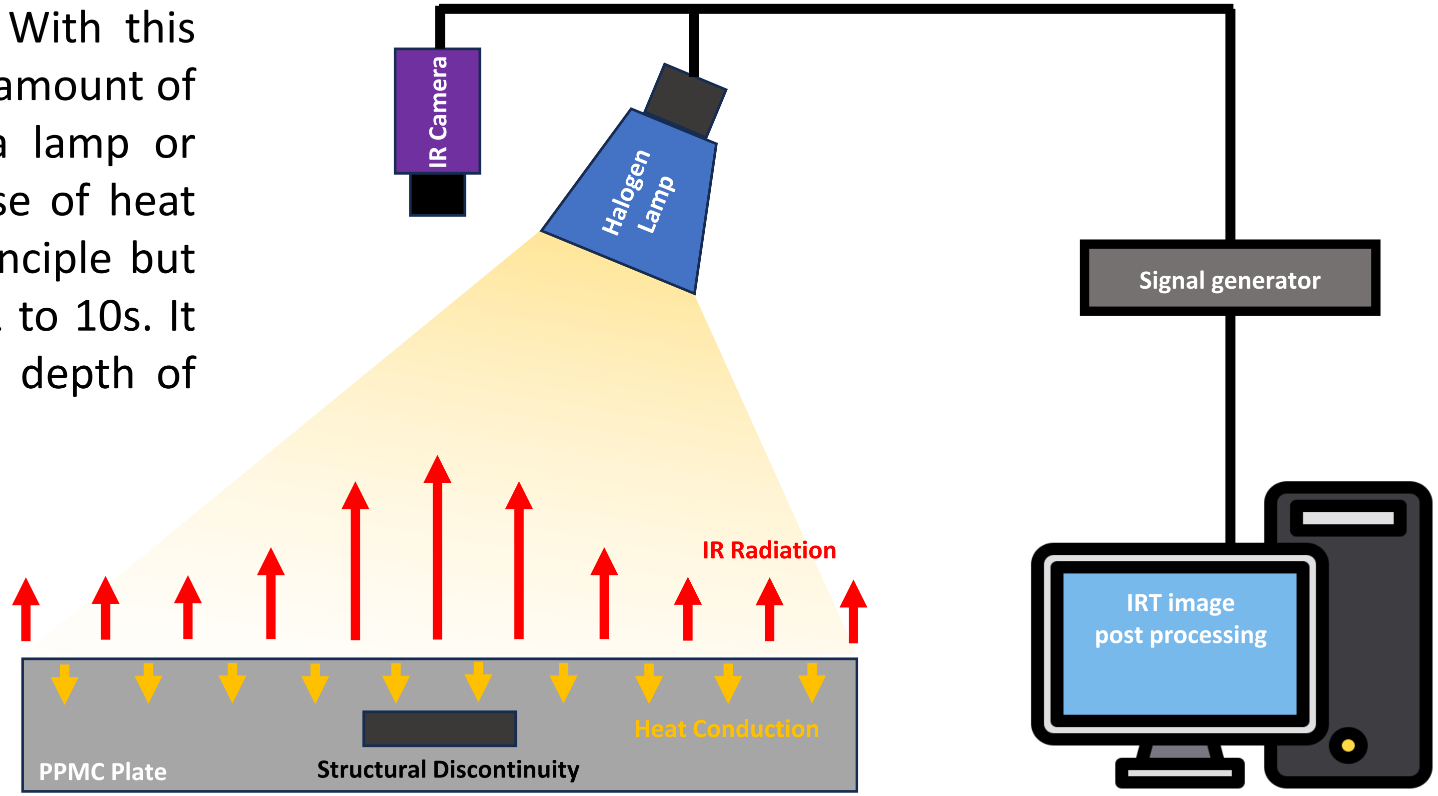
- It's the most simple technique. It measure the infrared temperature of a structure in absence of thermal stimulation.



INFRARED THERMOGRAPHY (IRT)

Pulsed and Transient Halogen Lamp Thermography

It's the most used technique in composites. With this technique the object is heated up for a certain amount of time from an external source, in this case a lamp or halogen lamp. The first one use a 2ms impulse of heat with lamps. The second one use the same principle but for a long time of exposure, usually between 1 to 10s. It depends on the power of the lamps and the depth of inspection.



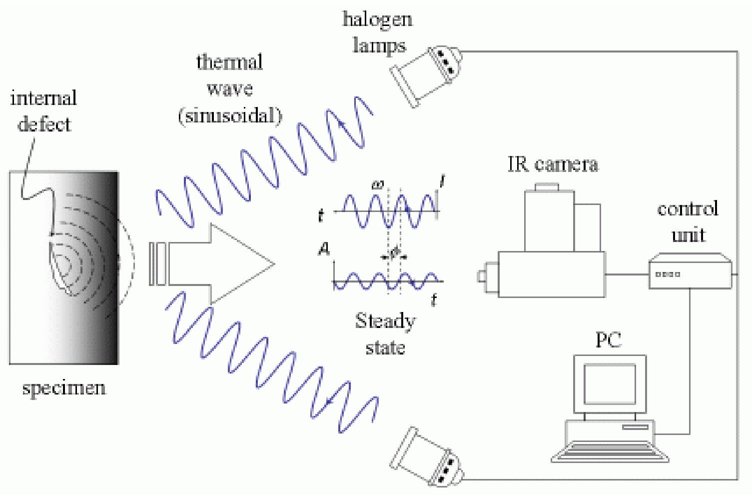
There are two kind of techniques of Post Productions:

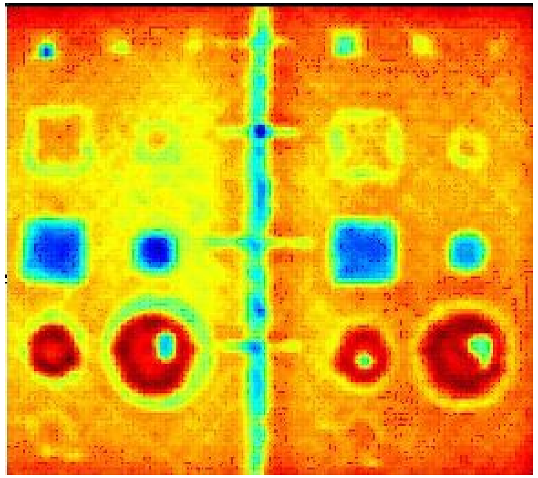
- Transmission;
- Reflection.

INFRARED THERMOGRAPHY (IRT)

Lock-In Thermography

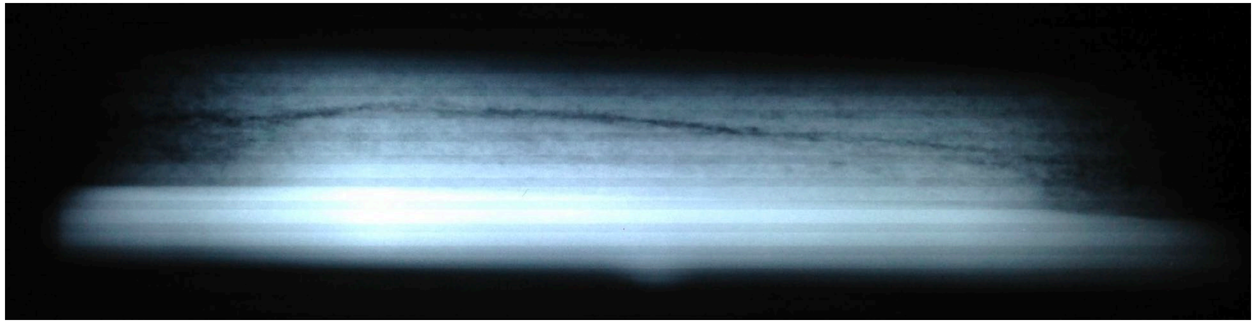
- With this technique the object is heated up for a periodic amount of time from an external source, in this case a flash lamp or halogen lamp.
- Is based on the sinusoidal modulation of the heating, which produces a thermal wave that propagates inside the object and is reflected when it encounters a discontinuity surface, for example due to the presence of a hypothetical delamination.

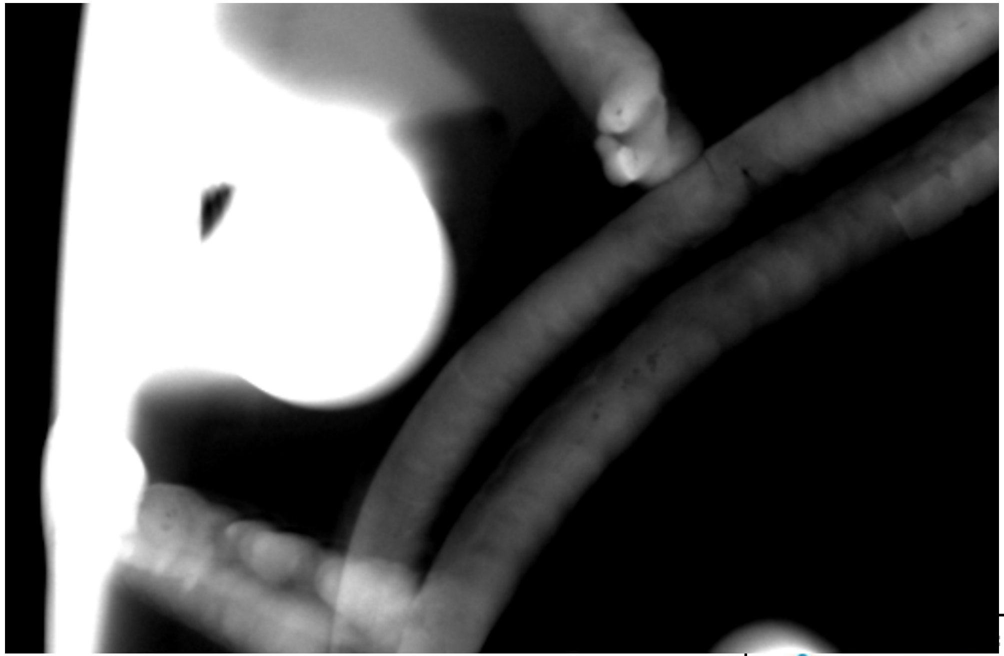




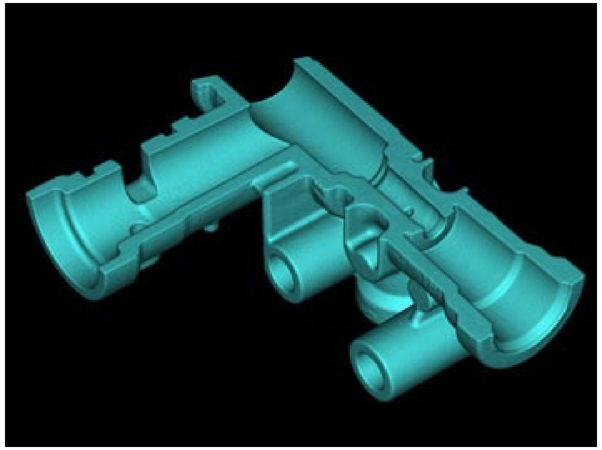
X-RAY

It is a volumetric method and it is one of the most used. With this method is possible to scan components with different thicknesses and shapes. Detectable defects are voids, cracks presence of foreign materials. It works with a radiographic film that is exposed to the radiation that passes through the test object. The detected discontinuities are visible with a different density with respect the surrounding material. Is limited in thickness based on material density, and there are problems with orientation of planar discontinuities. It has also the disadvantage of introducing safety issues and so it is mandatory to use special shields (e.g. lead walls), and the use of particular work procedure and clothes.





COMPUTED TOMOGRAPHY



Axial CT

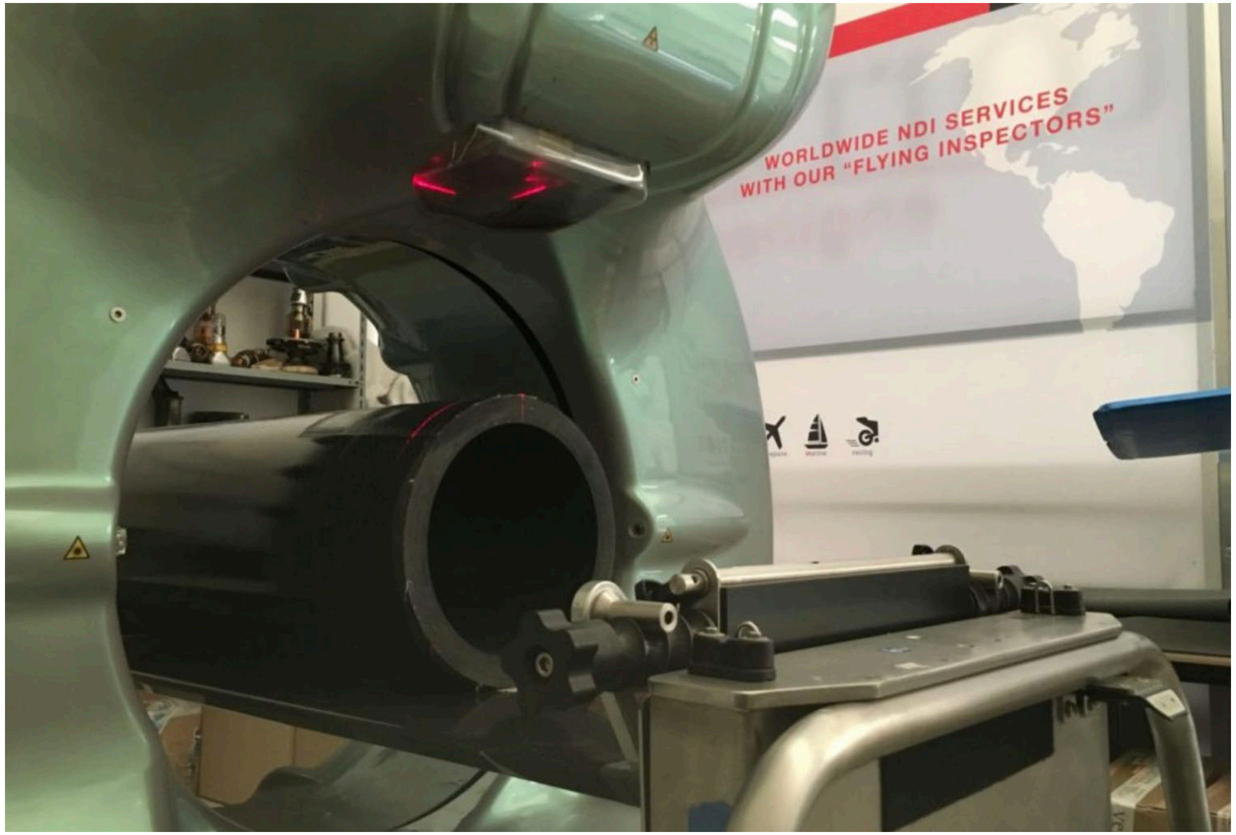
COMPUTED TOMOGRAPHY

Pros:

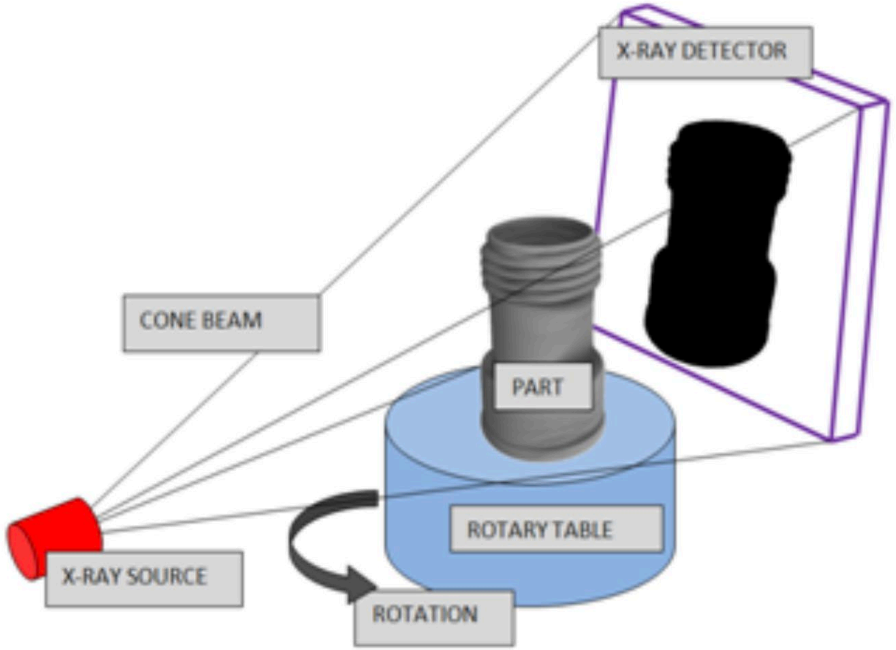
- Contactless
- Fast
- Portable?
- 3D
- Can be done in Real Time (Radiosopy)
- Non-invasive
- Info about the internal geometry
- High Accuracy (up to 5microns)

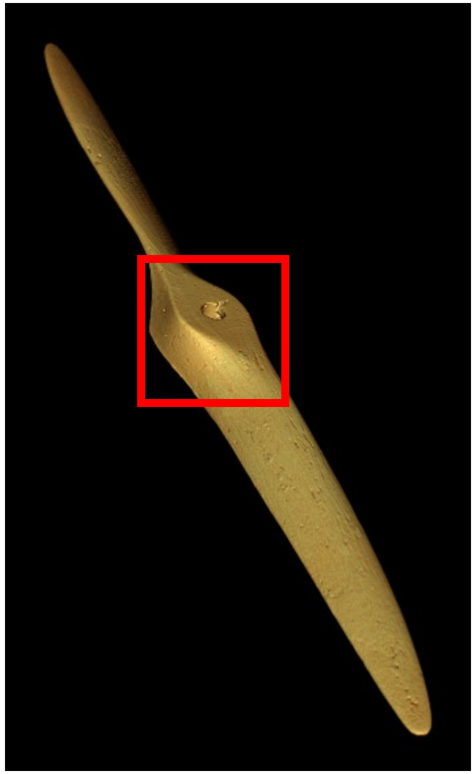
Cons:

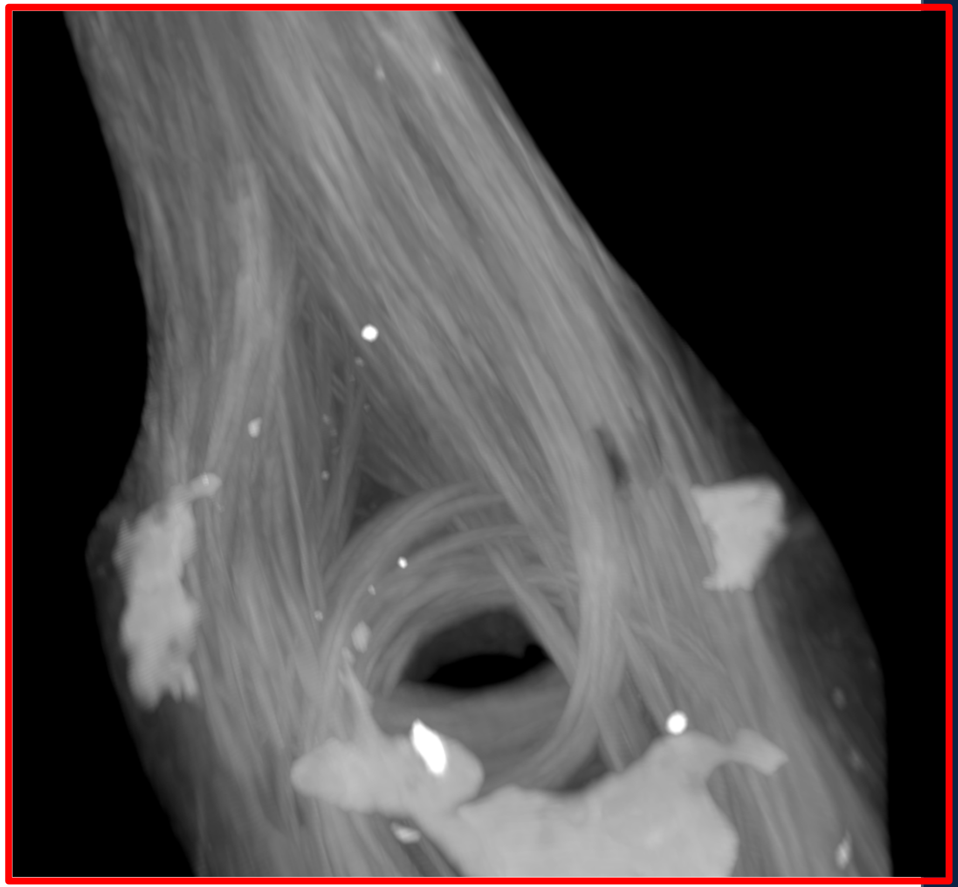
- Very Expensive
- Not good for parts with metal parts
- Can be dangerous for human



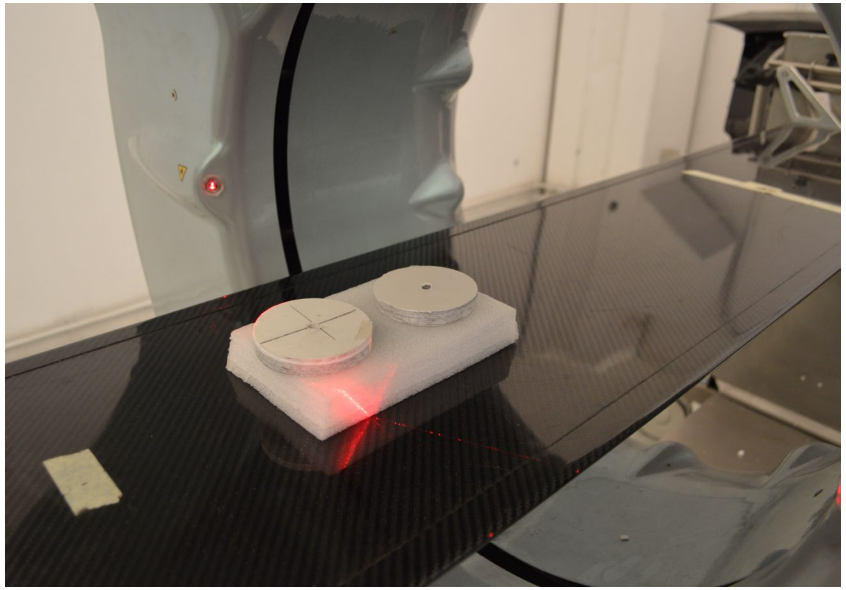
COMPUTED TOMOGRAPHY





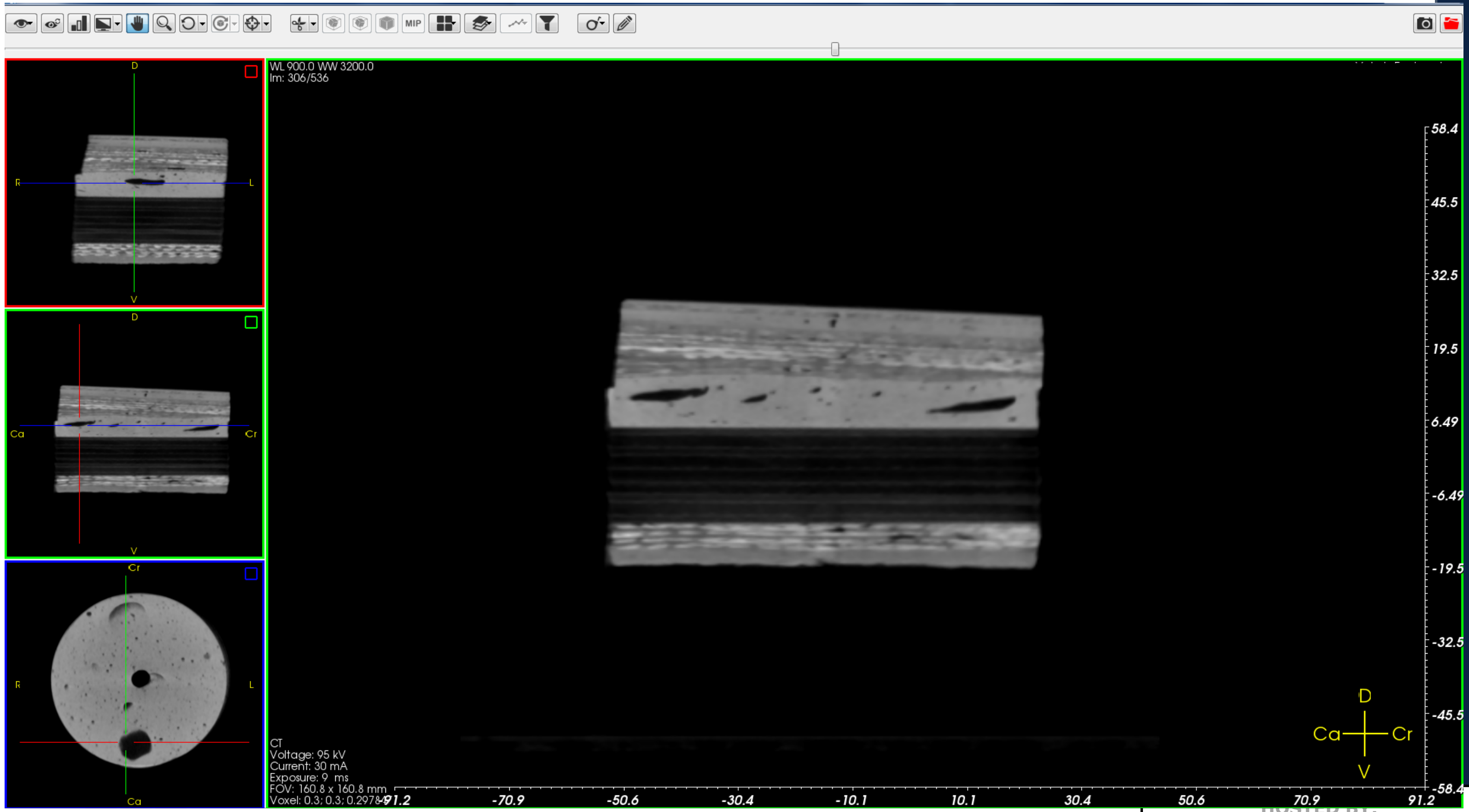


EXAMPLE: COMPUTED TOMOGRAPHY SCAN



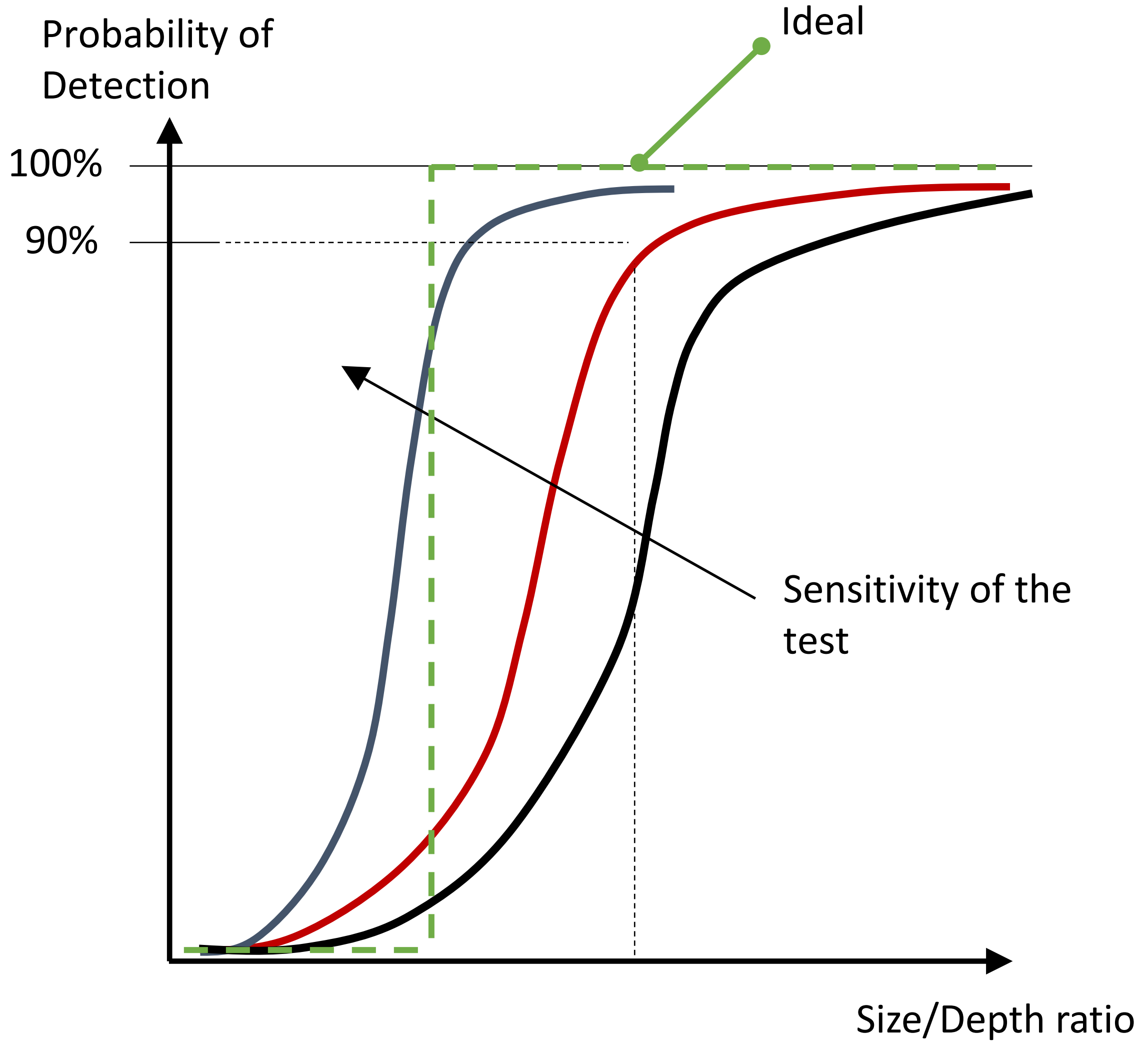
Axial CT specimen scan

Axial CT specimen post- production

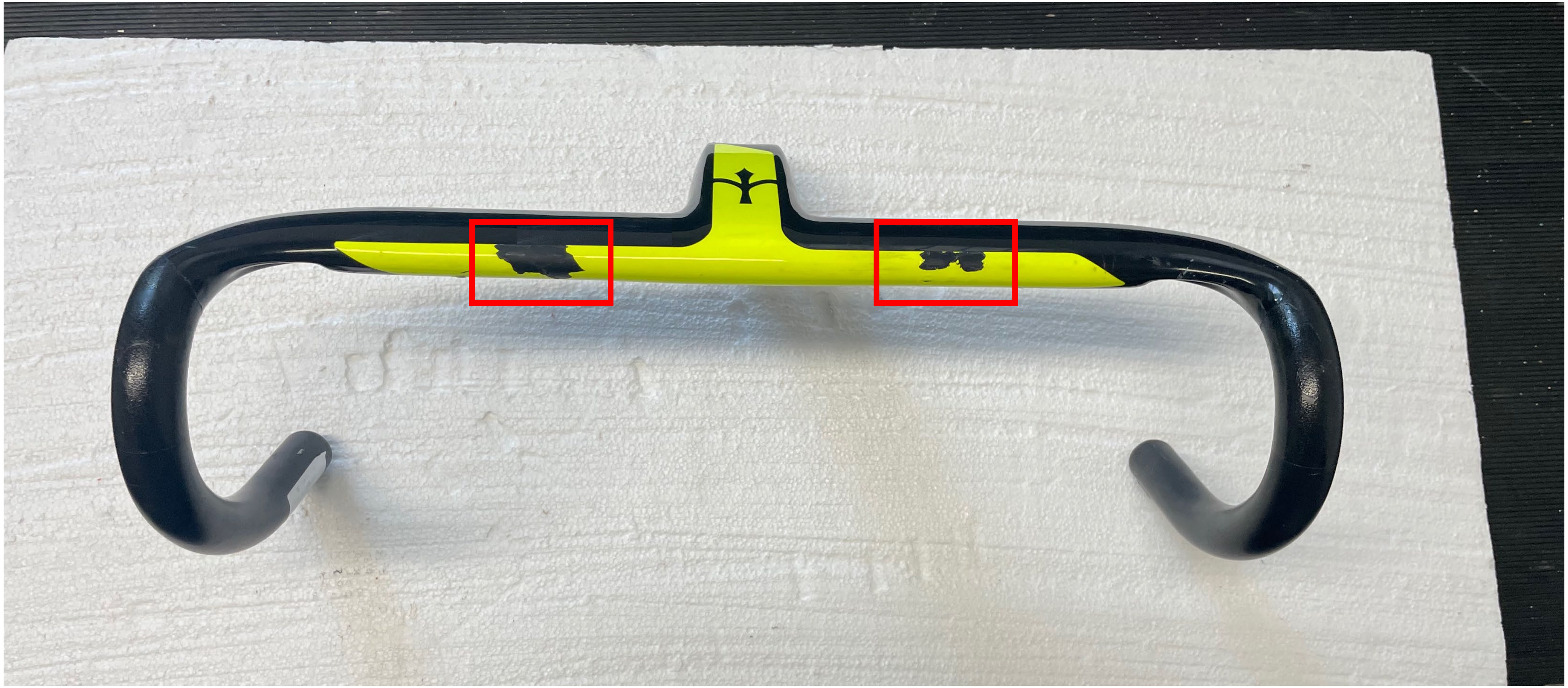


PROBABILITY OF DETECTION IN NON-DESTRUCTIVE TESTING

- Probability of Detection (POD) in Non-Destructive Testing (NDT) is a statistical measure that quantifies the likelihood of detecting defects within a part using a specific NDT method.
- It provides an estimate of a method's reliability by indicating the probability that a test will identify defects of a certain size or type under given conditions.
- In an ideal situation, the POD curve would represent a straight line at a certain defect size, indicating a 100% Probability of Detection for that flaw size.
- Typically, the POD curve forms an "S" shape: a steeper curve suggests higher sensitivity of the test, meaning the method is more likely to detect smaller or deeper defects.



CASE STUDY: BIKE ACCIDENT INSPECTION



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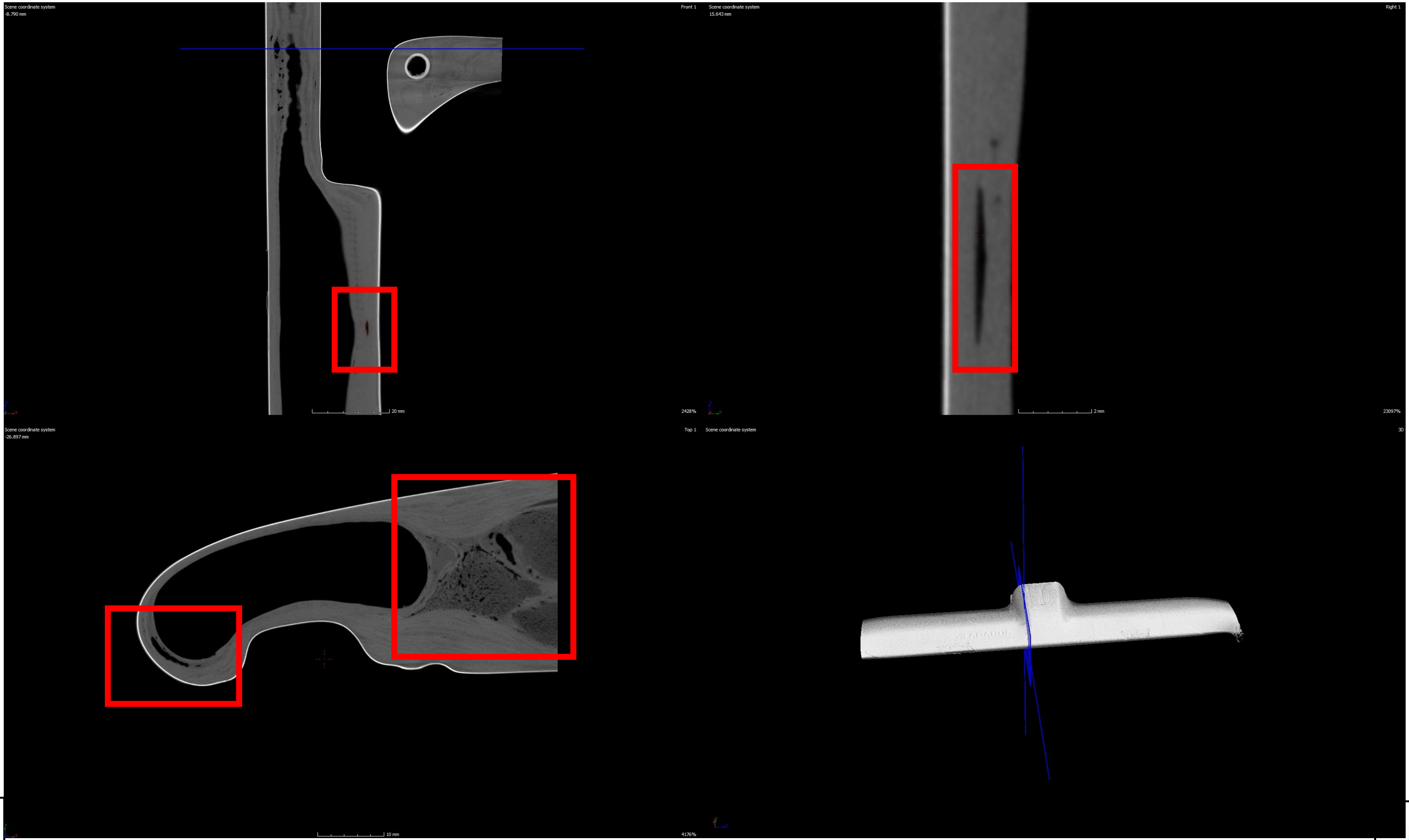
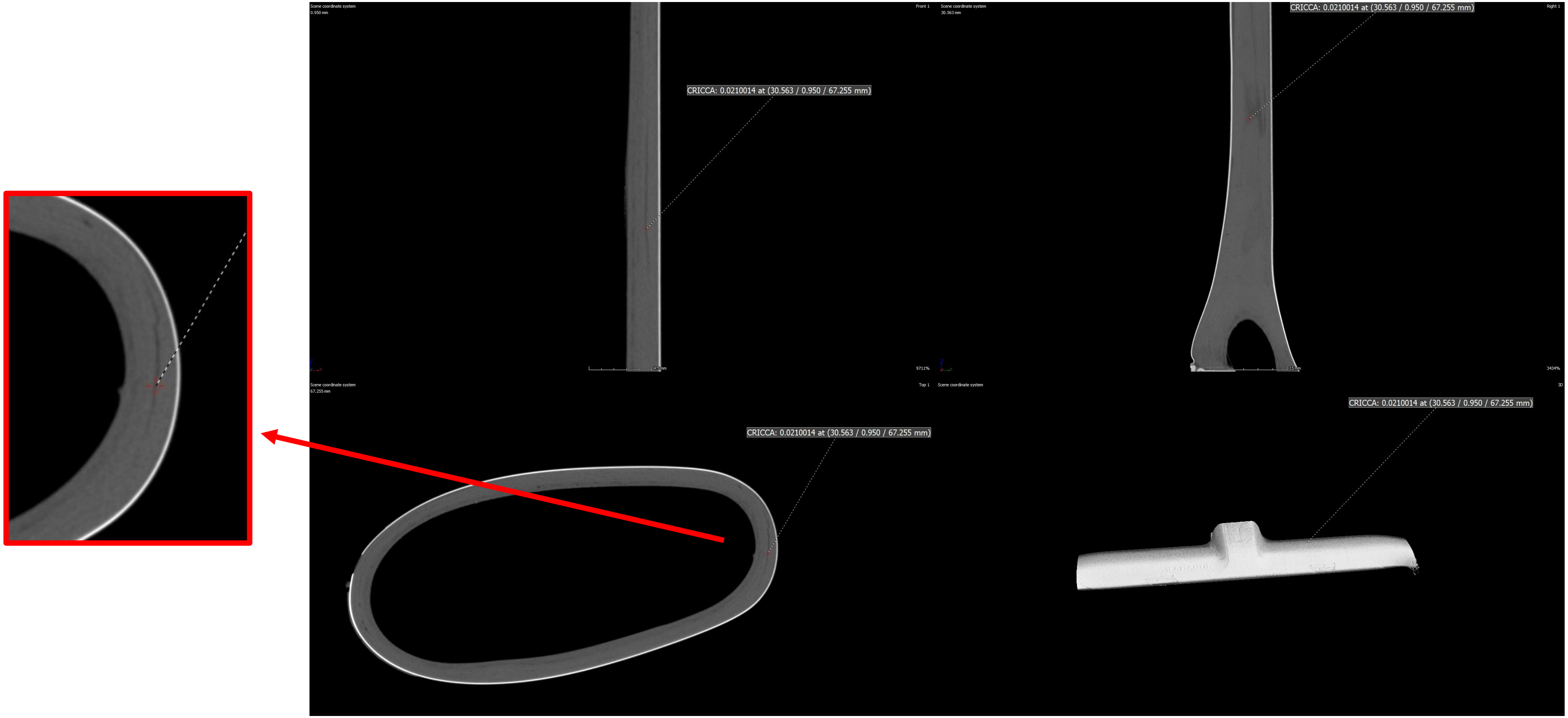
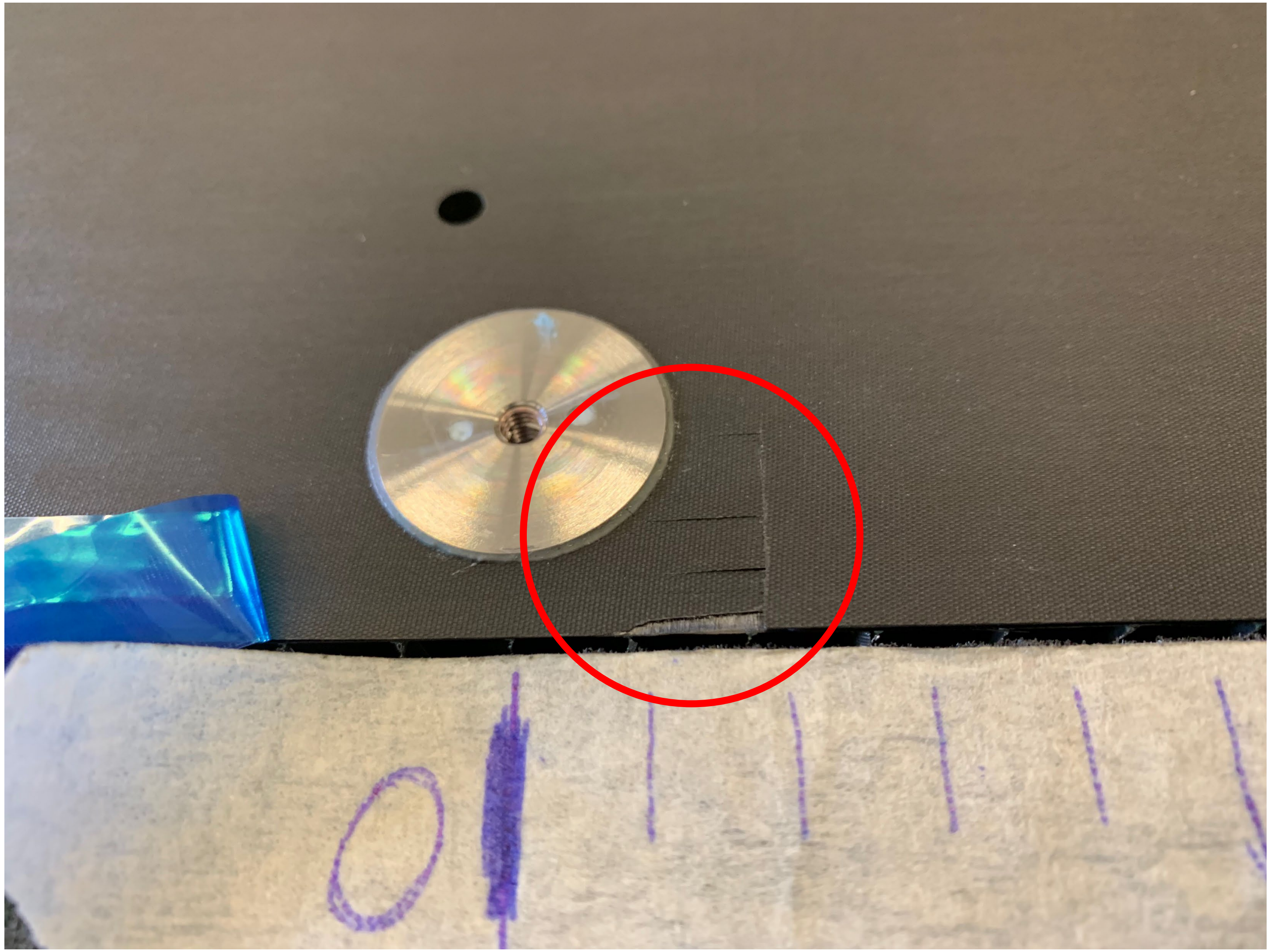
CASE STUDY: BIKE ACCIDENT INSPECTION



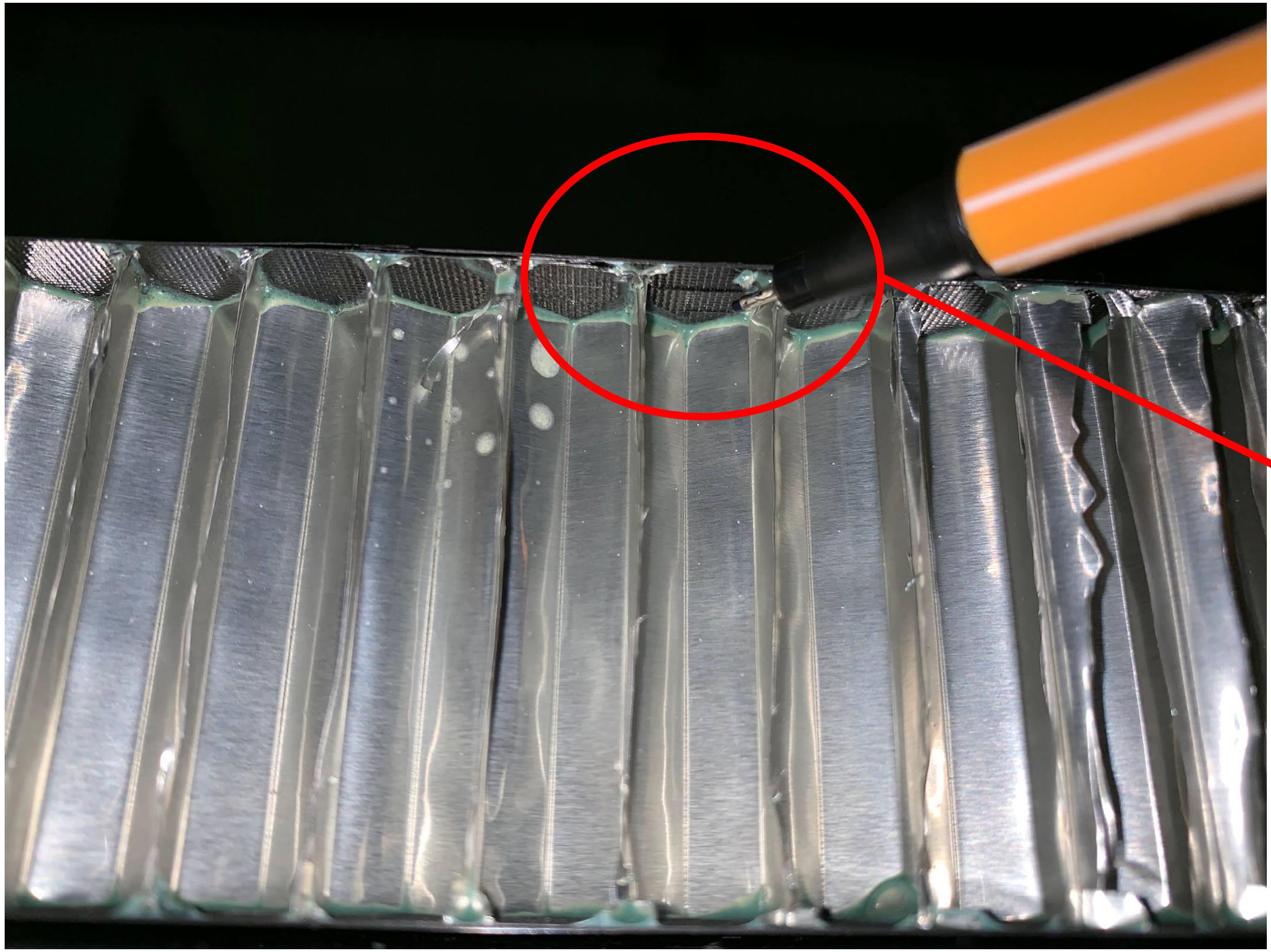
CASE STUDY: BIKE ACCIDENT INSPECTION

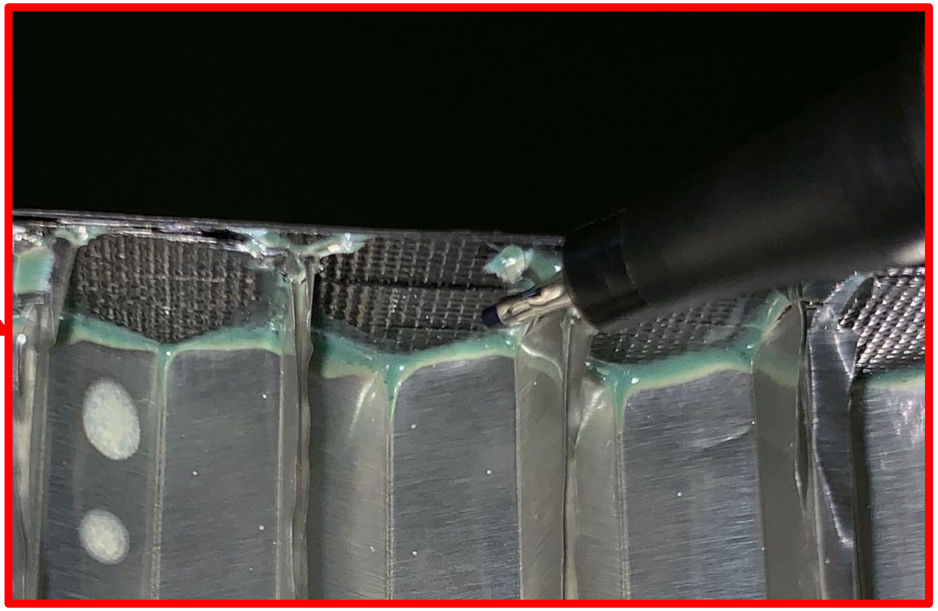


CASE STUDY: SATELLITE HONEYCOMB STRUCTURE WITH DAMAGE

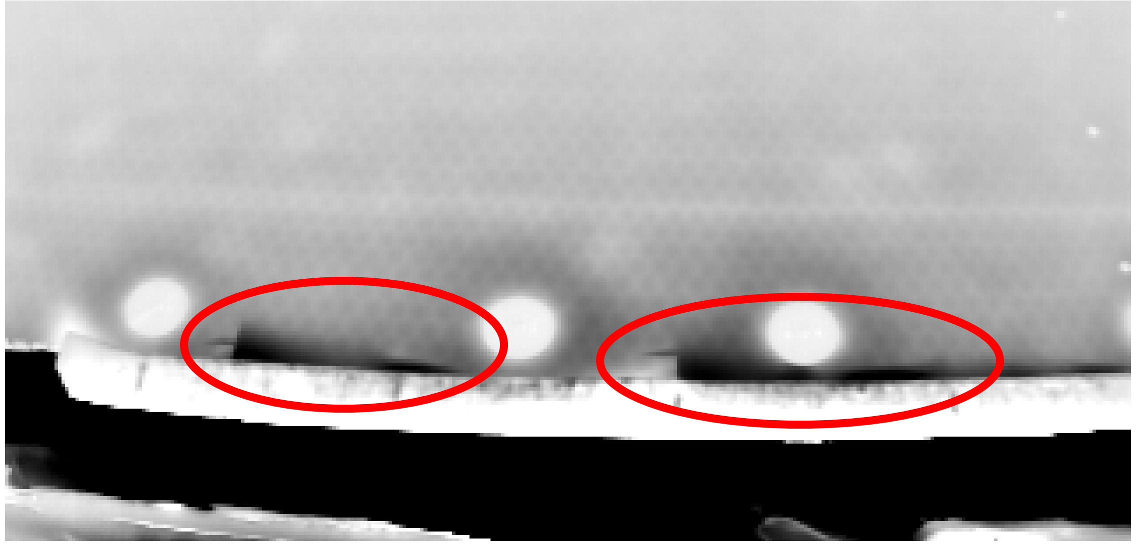


CASE STUDY: SATELLITE HONEYCOMB STRUCTURE WITH DAMAGE





CASE STUDY: SATELLITE HONEYCOMB STRUCTURE WITH DAMAGE



Thank you for joining us!

Keep an eye out for upcoming AIM events:

Repair of Sandwich Panels
Hosted by Dr. Casey Keulen
June 26, 2024
https://compositeskn.org/KPC/A368

And don't forget to visit the KPC for more information:

https://compositeskn.org/KPC

Today's Webinar will be posted at:
https://compositeskn.org/KPC/A366

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