Multi-dimensional data fusion study for ultrasonic and radiographic non-destructive inspections

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Abstract: Multi-layered structures of adhesively bonded metals, composites or dissimilar materials are advanced structures which are very attractive for aerospace industry. Adhesive joints are superior joining technology providing homogenous load distribution, resistance to corrosion and ability to join dissimilar materials. However, their usage in aerospace industry is significantly limited due to the lack of reliable non-destructive evaluation methods. In addition, the requirements of accuracy and reliability are always increasing in aerospace.
Data fusion of various non-destructive evaluation methods is employed in order to increase the reliability of the testing. The data fusion technique involves processing and analysis of the data from multiple sources as well as their combination what leads to the signal enhancement, decrease of uncertainty, and provides better evaluation results.
The objective of the work is to perform multi-dimensional data fusion of the results collected from ultrasonic and radiographic inspections of layered structures in order to increase reliability of the technique.
The experimental investigation of adhesively bonded materials containing artificial defects was performed using ultrasonic and radiographic non-destructive testing methods. In addition, the modelling and inspection simulations of the methods were performed for the analysis in order to improve the feature extraction and determine the results of their combination. As a result, amplitude of signal reflection and time of flight are the features which were used for data fusion. The advanced data processing technique was developed for the data fusion. The validation and verification of the technique was performed as well as the defects were sized.
As a result, application of multi-dimensional data fusion of different non-destructive methods has provided better evaluation results and increased the reliability of the technique.

Keywords: reliability, Adhesive Joints, Radiography, ultrasonic, 3D data fusion

Multi-dimensional data fusion study for ultrasonic and radiographic non-destructive inspections

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Why do we need data fusion?

Object of interest - Adhesive joints

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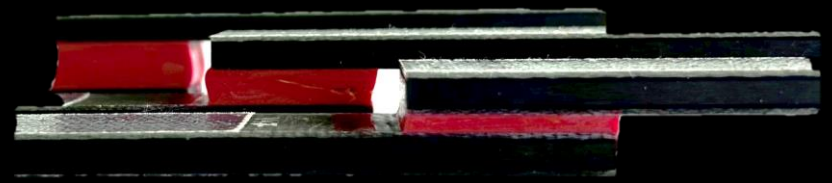
Advantages of adhesive joints:

- ✓ Can join wide range of materials
- ✓ Allow joining dissimilar materials
- ✓ Distributes stress more evenly – enhanced fatigue resistance
- ✓ Excellent load bearing capacity
- ✓ Can simplify assembly process – faster production, reduced costs
- ✓ Weight reduction
- ✓ More environmentally friendly

Disadvantages of adhesive joints:

- ➢ Sensitivity to aging, degradation
- ➢ Sensitivity to temperature
- ➢ Surface preparation
- ➢ Strength variability



Defects in adhesive joints

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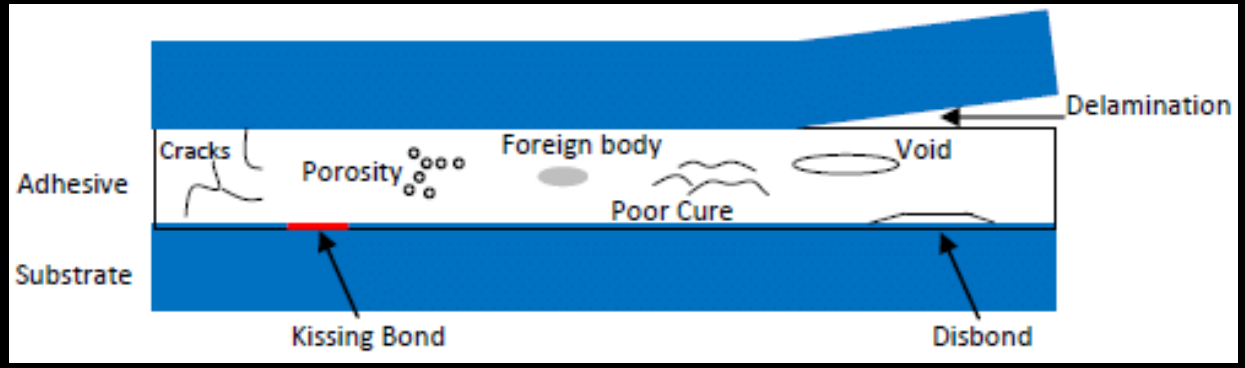
- Disbonds
- Inclusions
- Voids/porosity
- Weak bond due to surface contamination
- Weak joint due to improper curing conditions



Reliable NDT techniques are required to detect all types of defects or weak bonds

Ultrasonic vs Radiography

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Ultrasonic:

ADVANTAGES

- ✓ Sensitive to elastic properties and density
- ✓ Good at detecting planar defects, such as lack of bonding/delamination

DISADVANTAGES

- ➢ Challenges inspecting anisotropic, materials
- ➢ Orientation sensitivity
- ➢ Challenges inspecting weak bonds

Radiography

ADVANTAGES

- ✓ Sensitive to changes in density
- ✓ Good at detecting volumetric defects
- ✓ Good at detecting inclusions

DISADVANTAGES

- ➢ Difficulties inspecting thin objects
- ➢ Limited performance on planar defects
- ➢ Orientation sensitivity
- ➢ Challenges inspecting weak bonds

Data fusion

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Data fusion is the process of integrating and combining data from multiple sources to generate more comprehensive and accurate information.

- Improved accuracy
- Reduced uncertainty

Objective

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To develop novel **multidimensional data fusion method** for processing of the measurement data received from different NDT techniques (**ultrasonic and X-ray**) in order to achieve the reliable nondestructive evaluation (NDE) of the **adhesive joint integrity** to increase their application areas.

Samples

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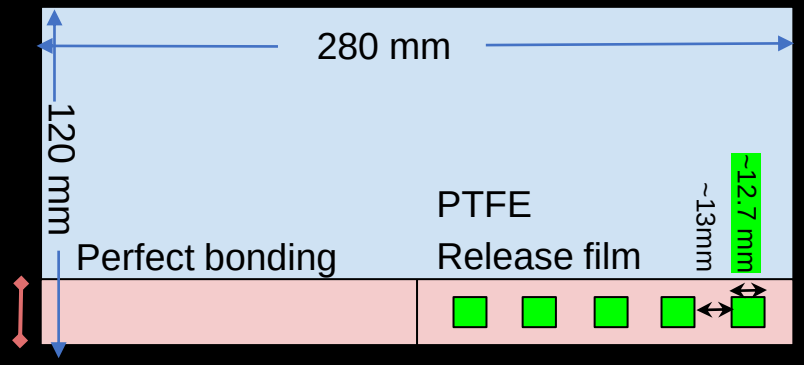
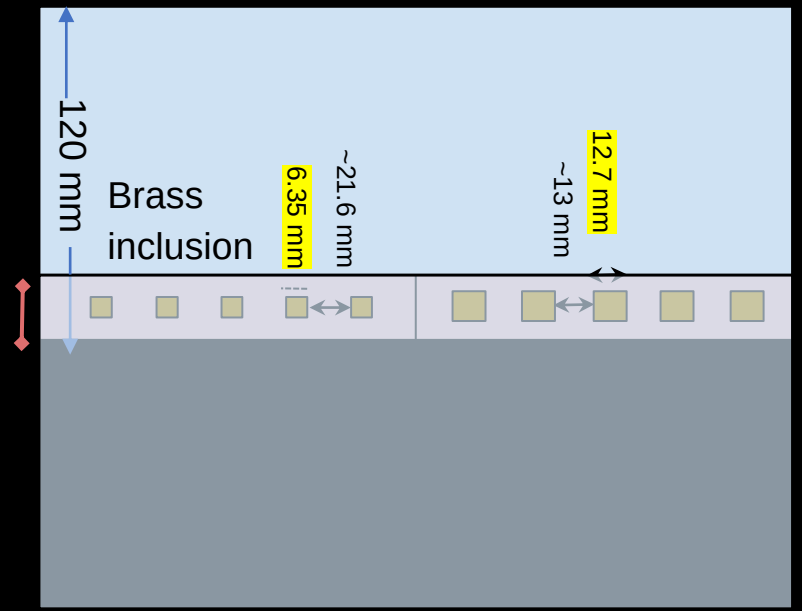
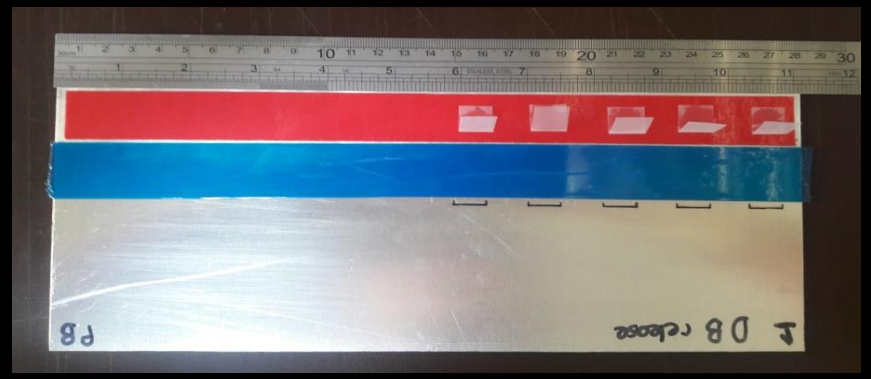
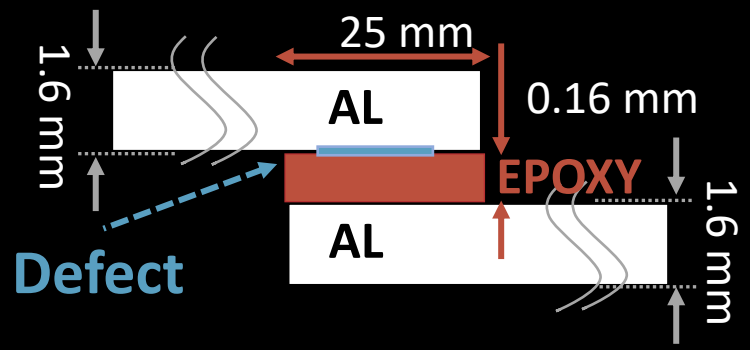




Adhesive single lap joints

Adherent type - Aluminum
Adhesive – AF163 epoxy:





Bonding quality:

- PB - Perfect bond
- DB – artificial disbond
- Brass film inclusion

Data fusion steps

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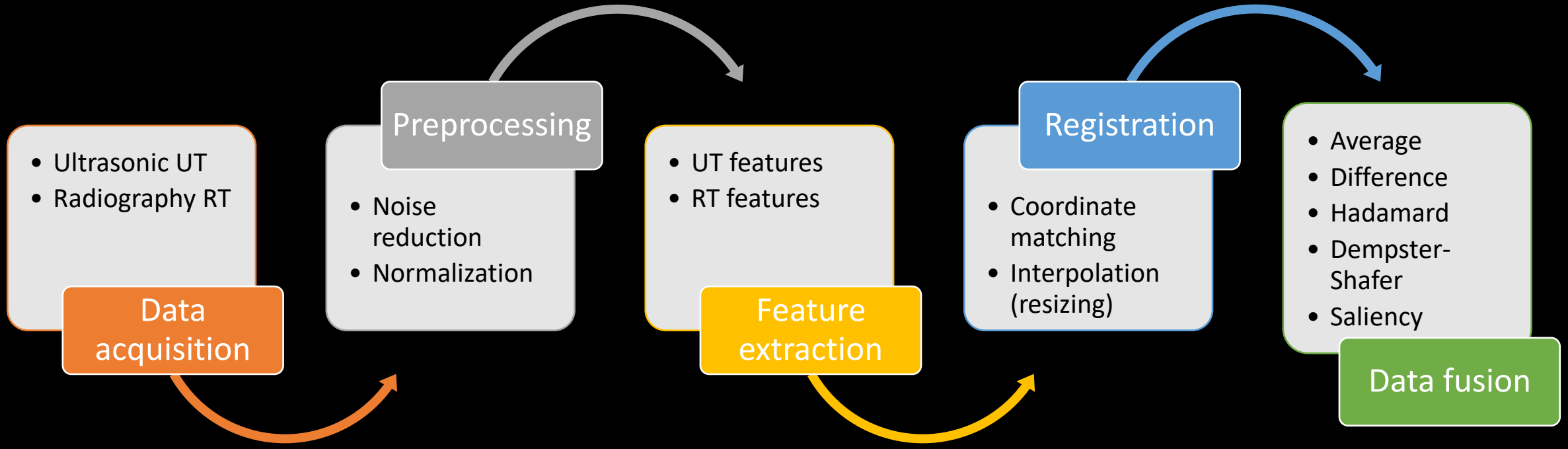

Data acquisition

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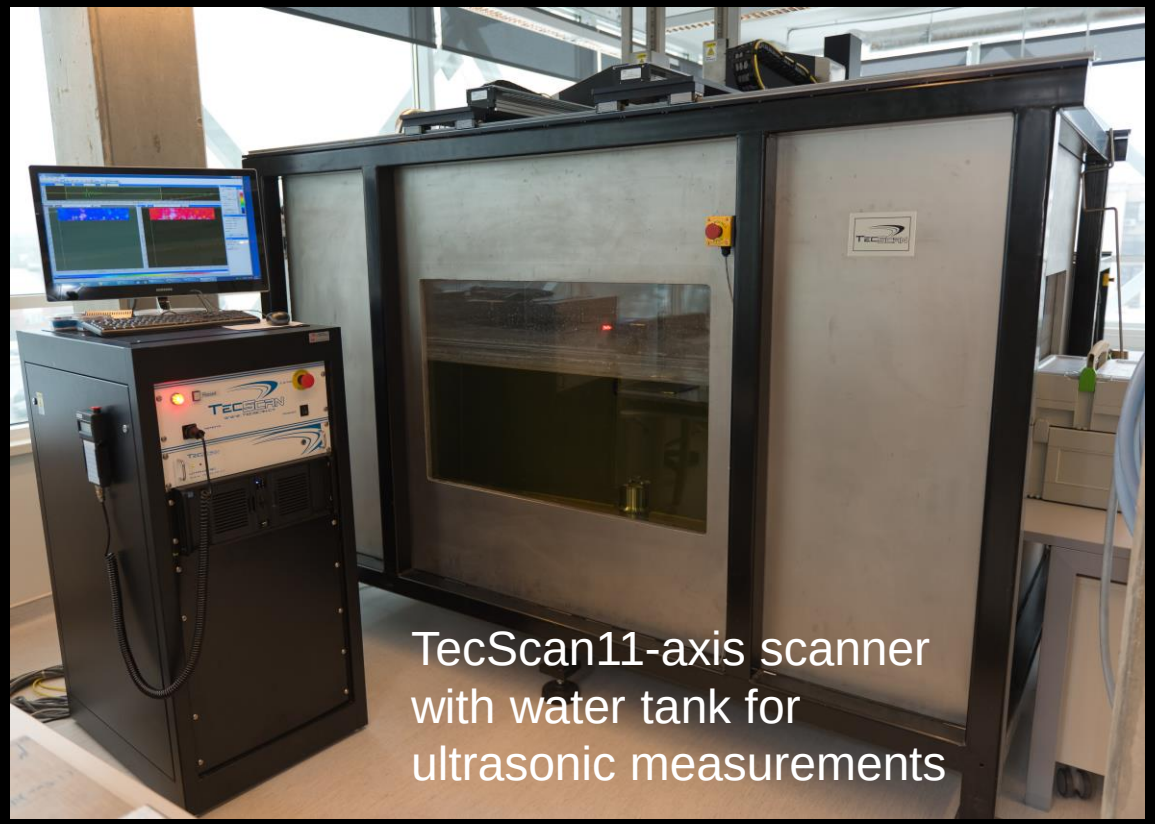
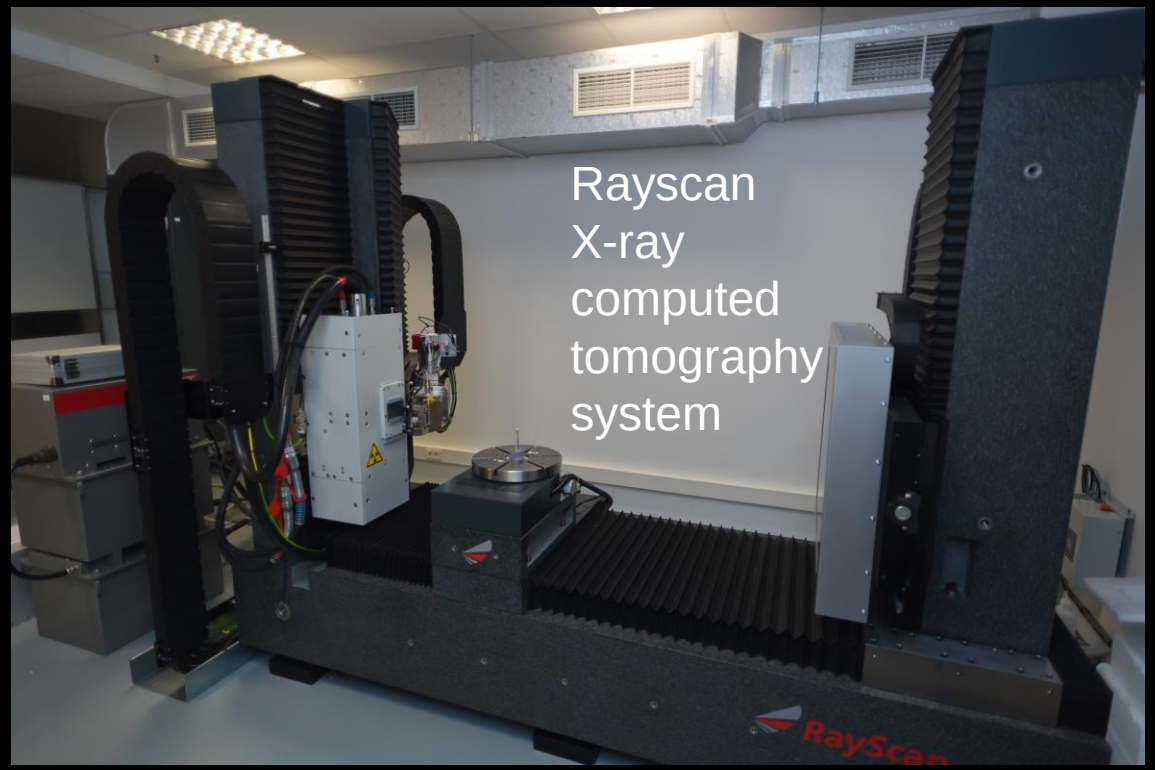
Ultrasonic testing



TecScan11-axis scanner with water tank for ultrasonic measurements

Radiography



Rayscan X-ray computed tomography system

Ultrasonic inspection

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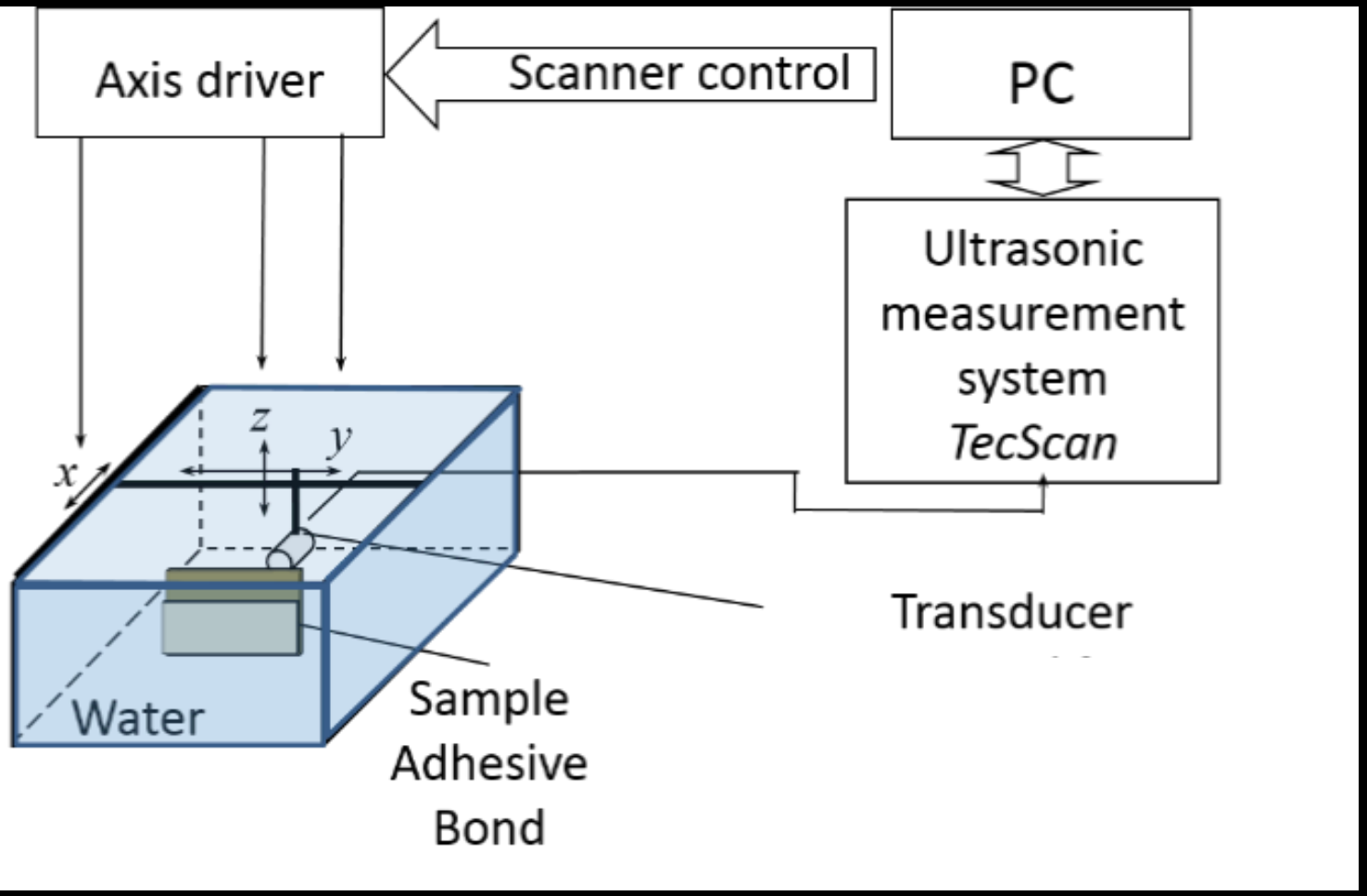

Immersion
pulse echo
15MHz, focused

0.2mm step

Radiography

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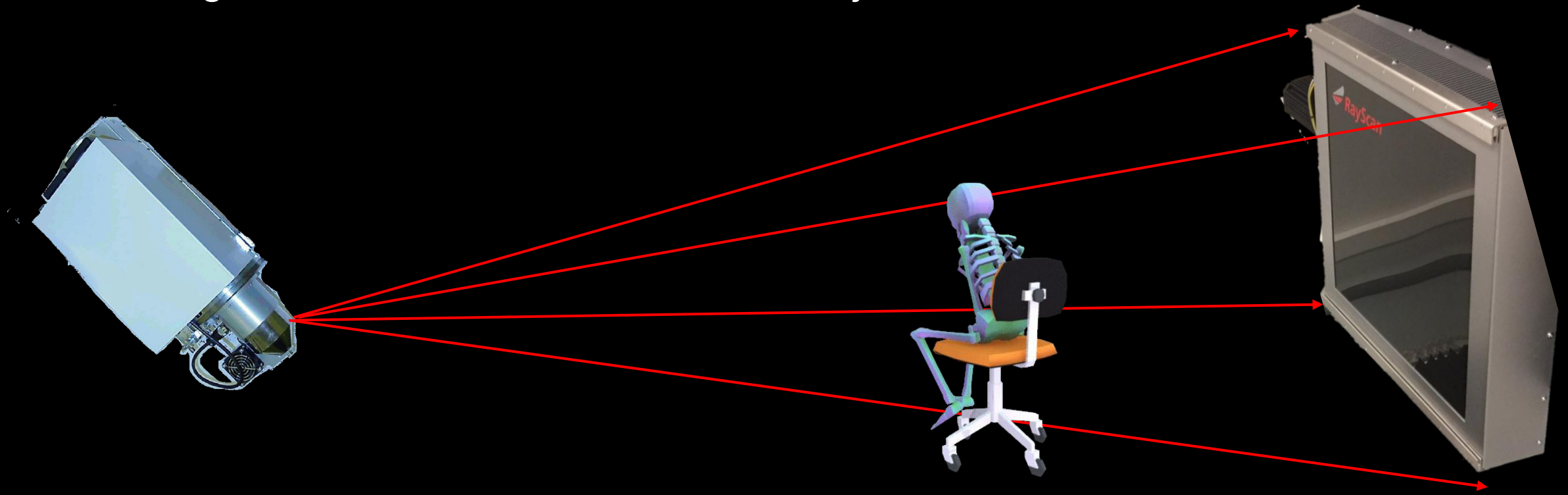
Radiography – is imaging technique that uses X-rays to create a 2D image of an internal structure of an object



RT results

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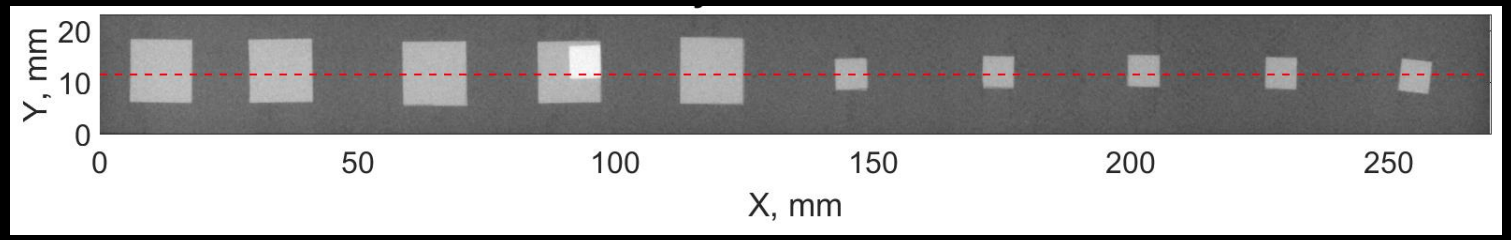
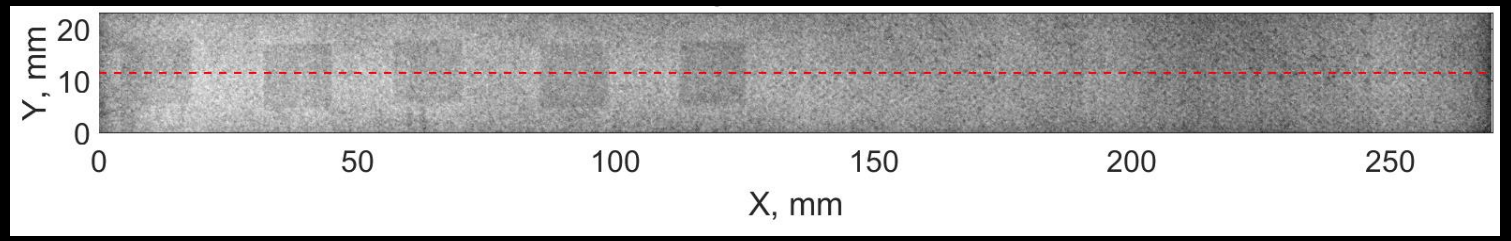
Inclusion



Disbond



Measurement parameters:

Voltage	150 kV
Current	300 µA
Integration time	1500 ms
Resolution	145 µm

UT results

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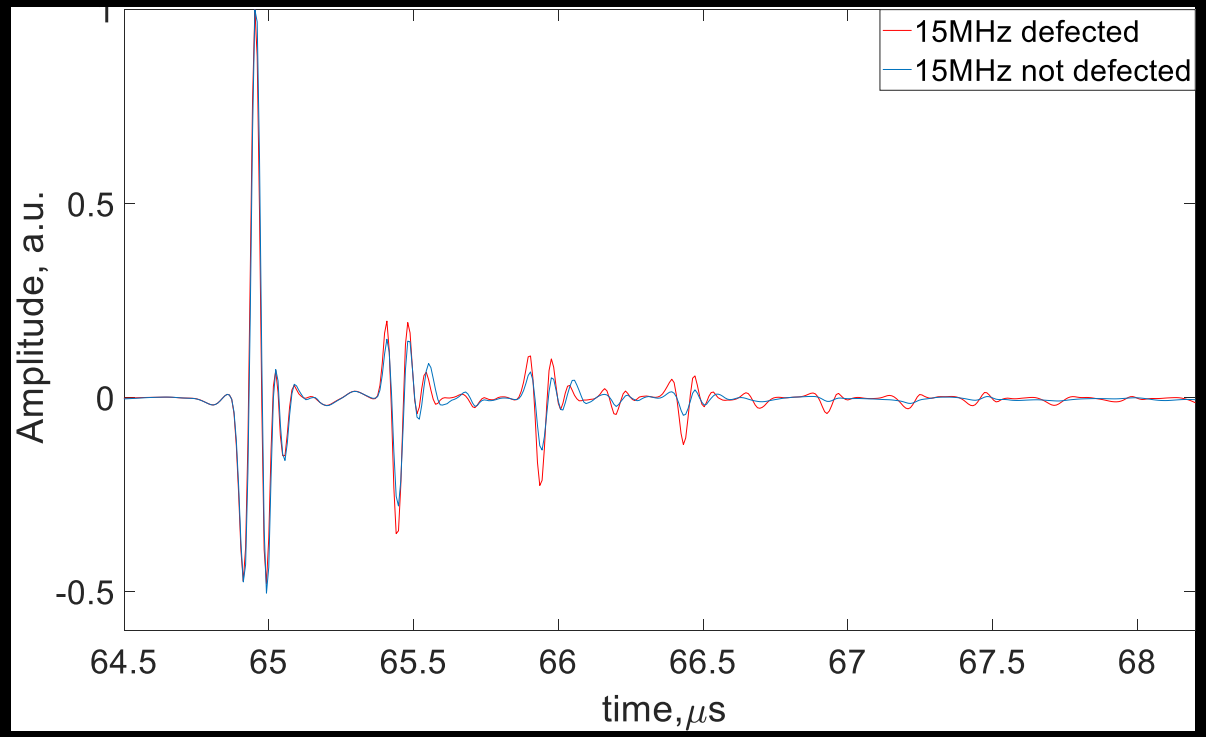
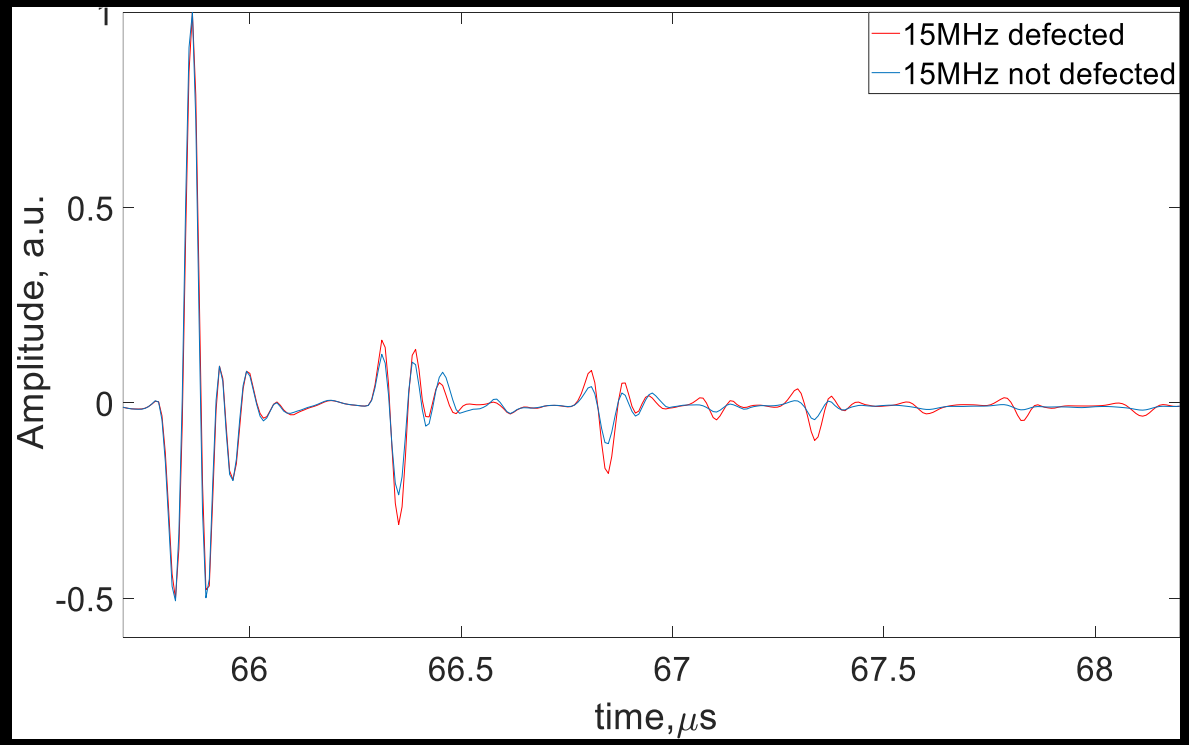
Inclusion



Disbond



UT propagation – theoretical analysis& modelling

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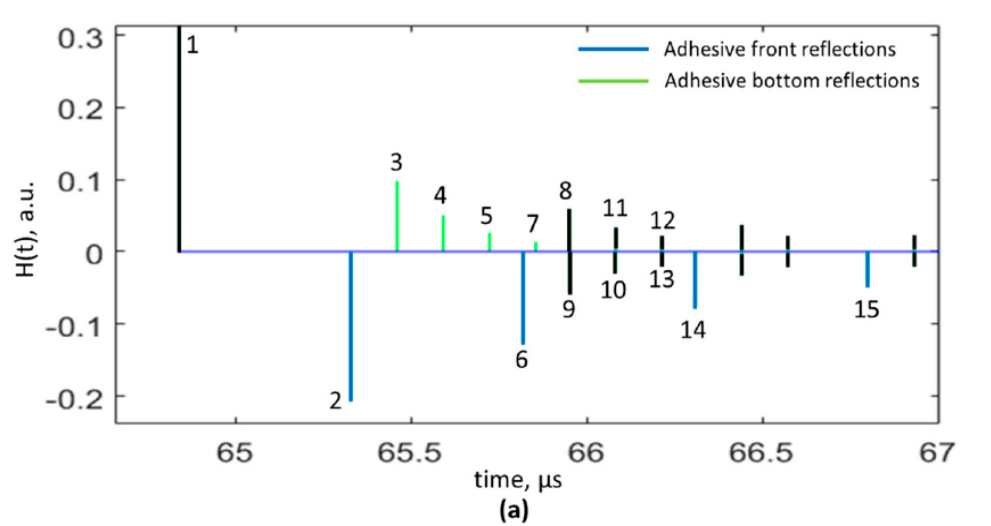

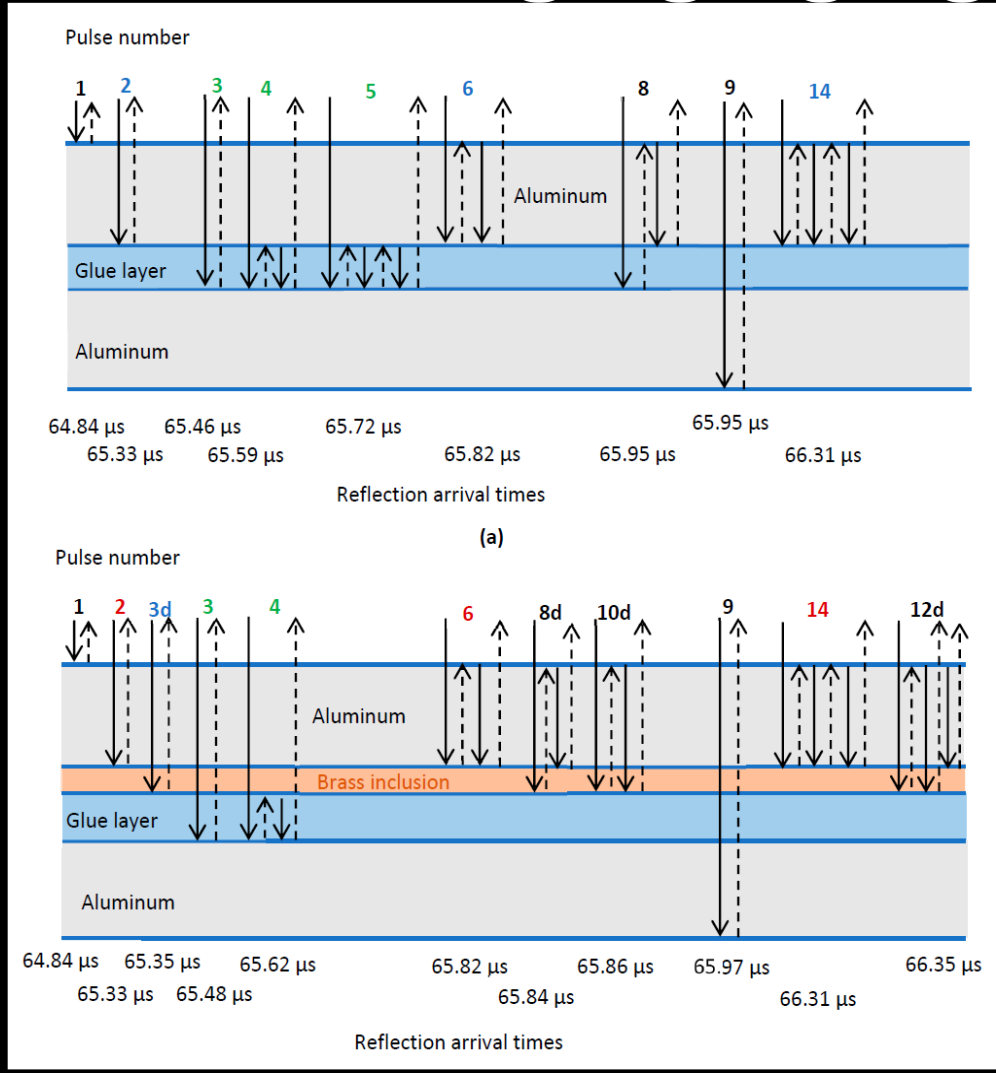

UT propagation – modelling vs experimental data

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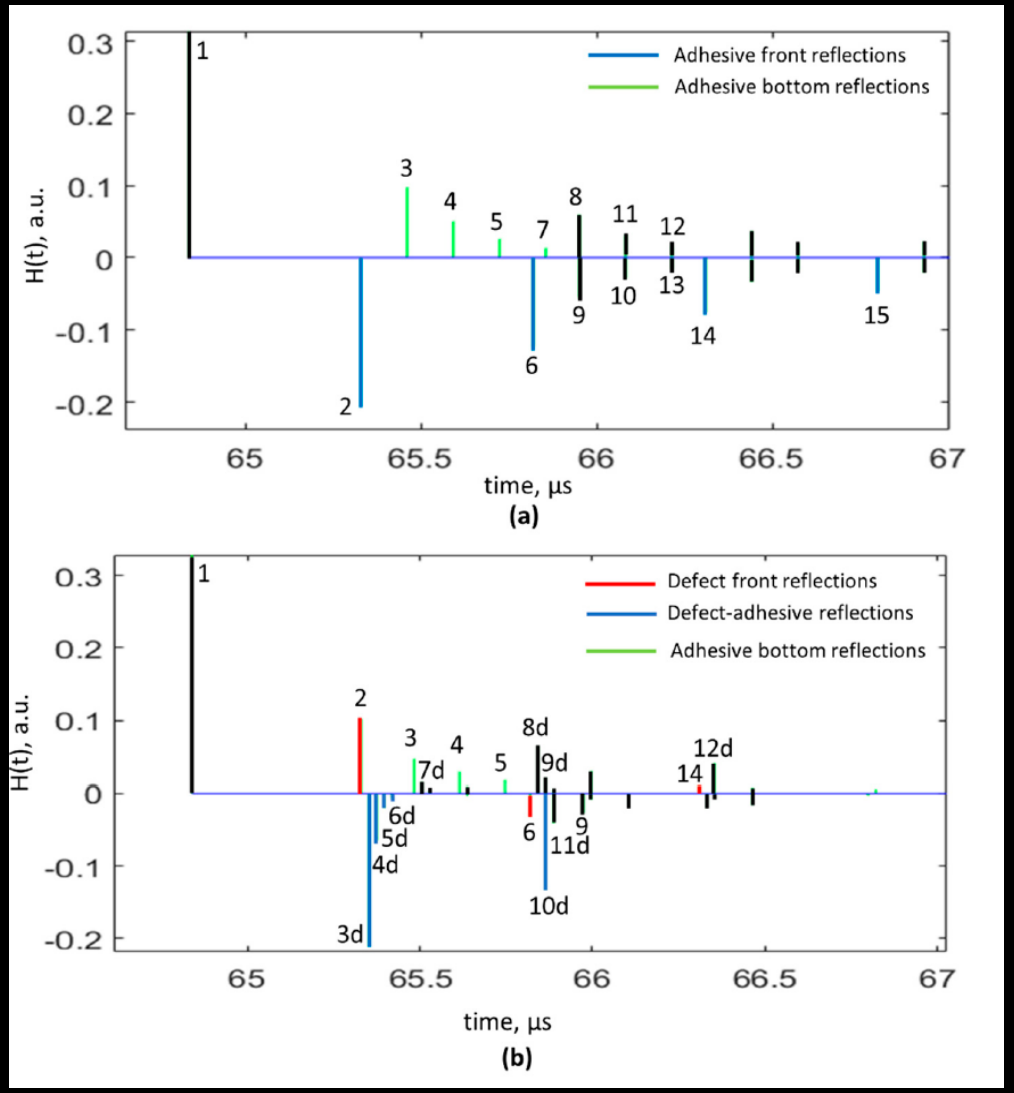

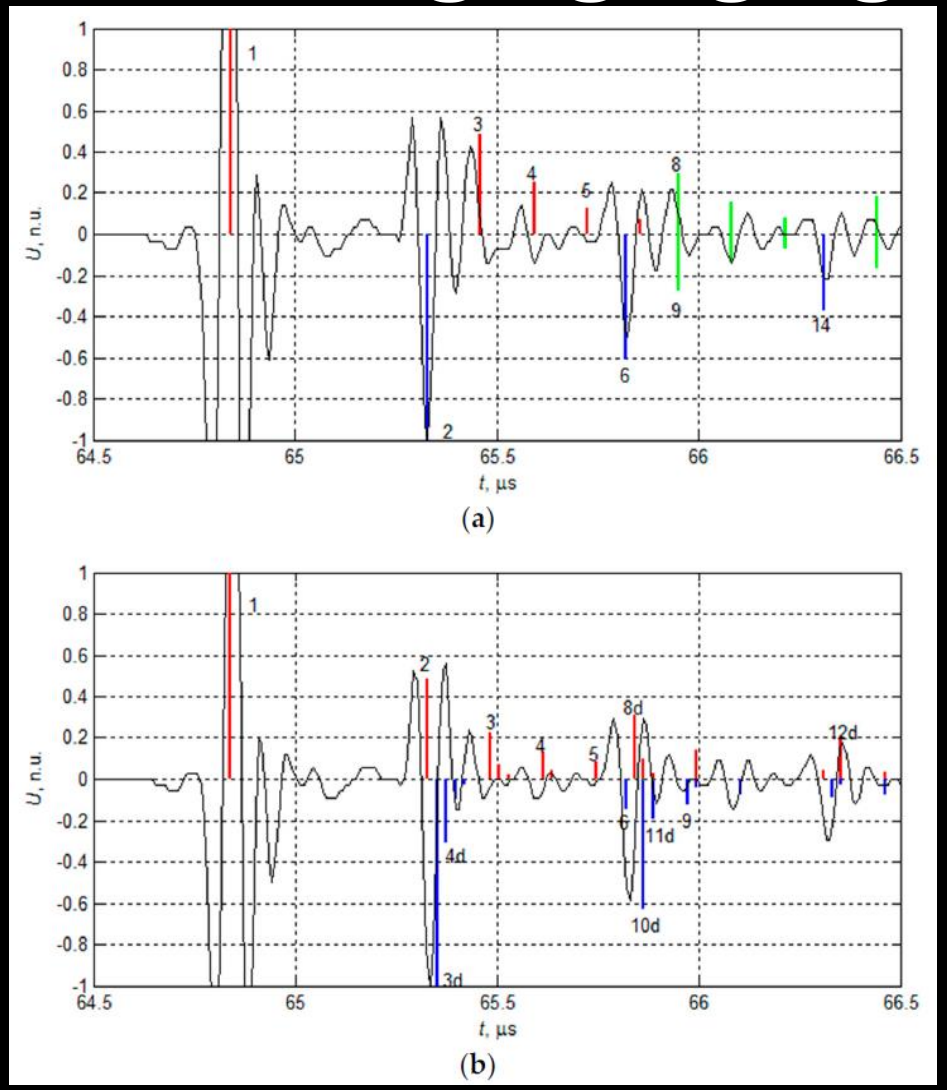

UT results

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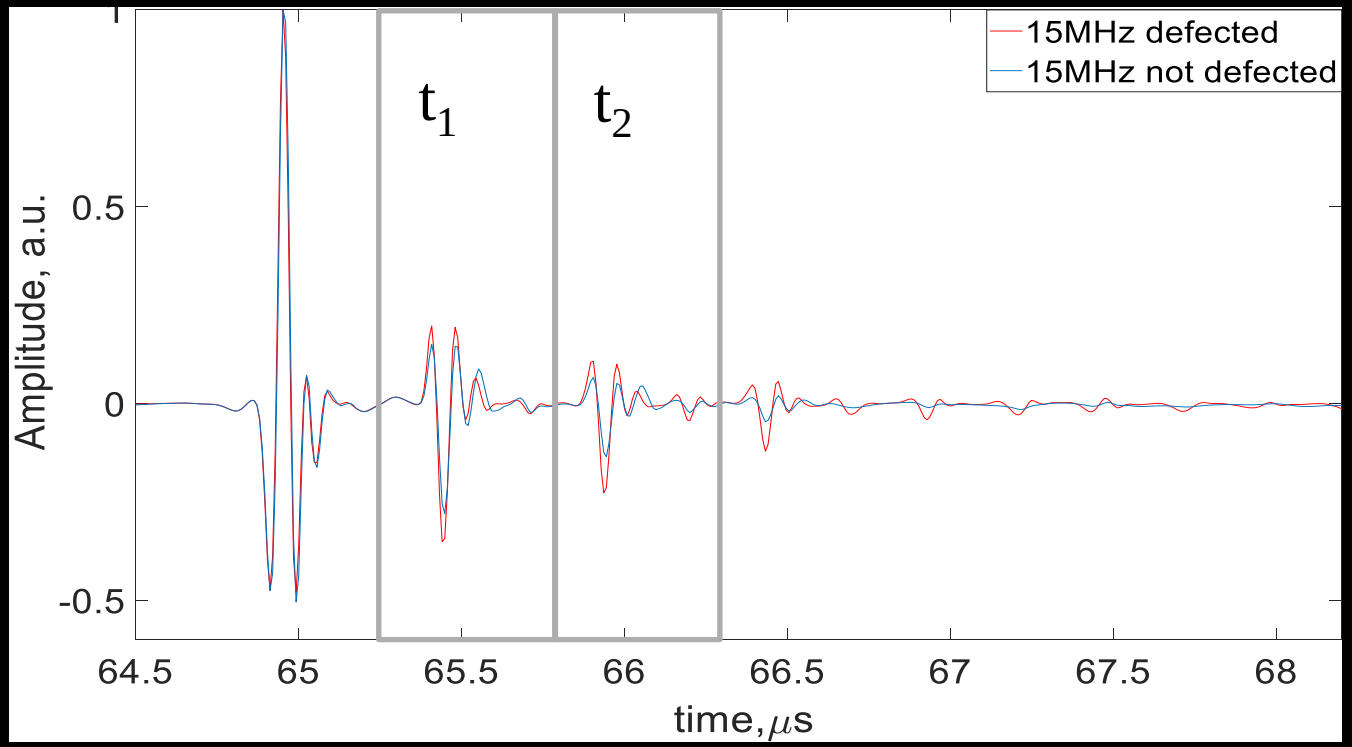
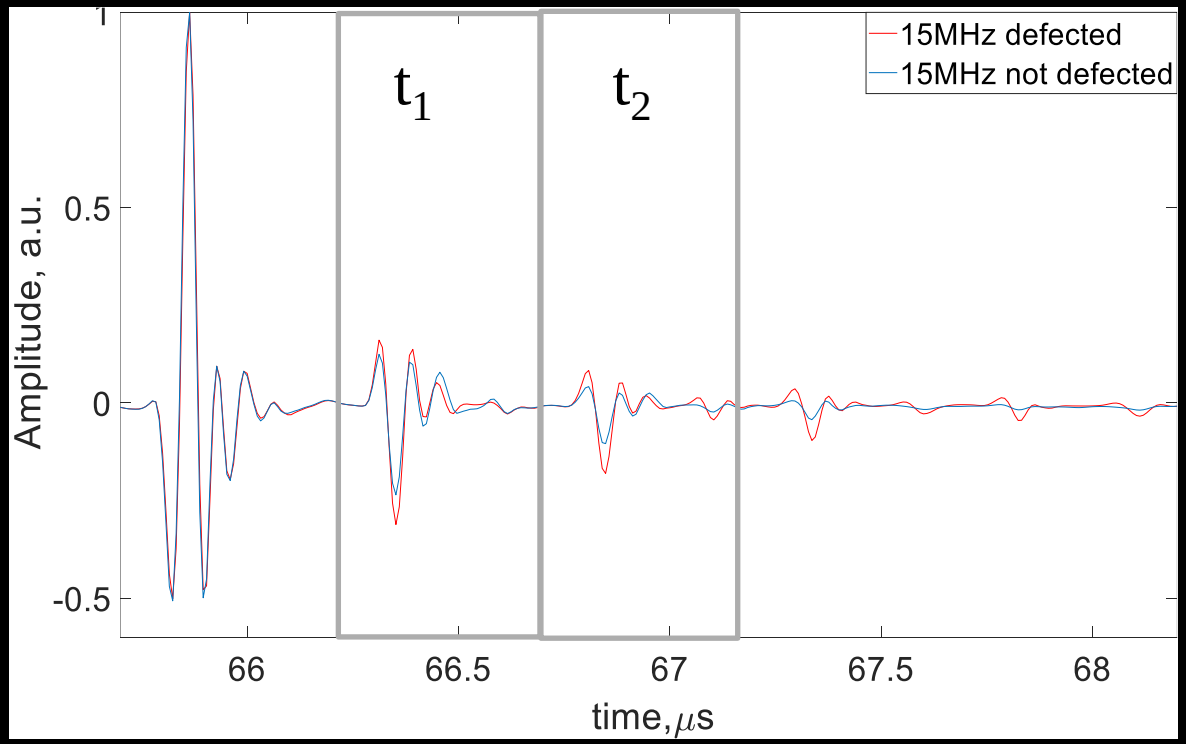
Inclusion



Disbond



Feature extraction

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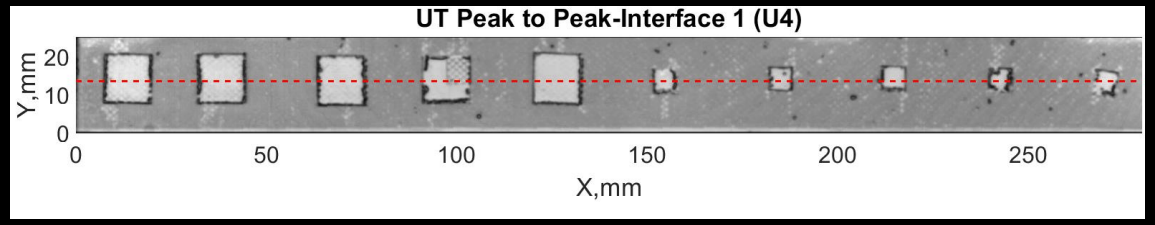

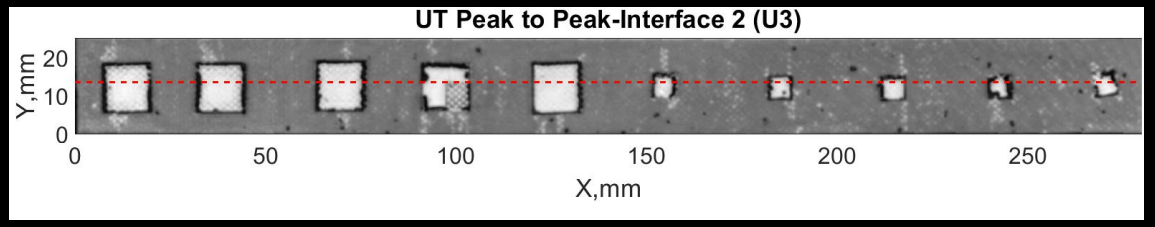

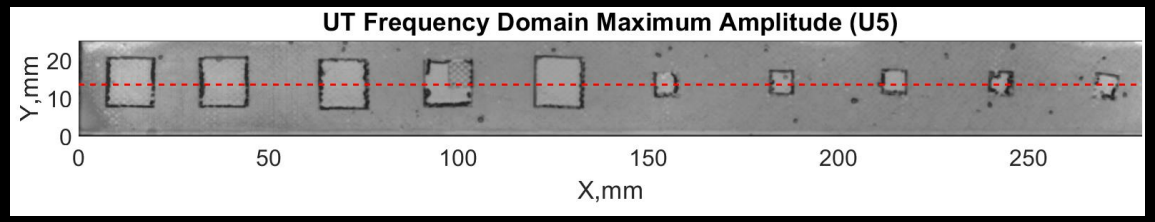

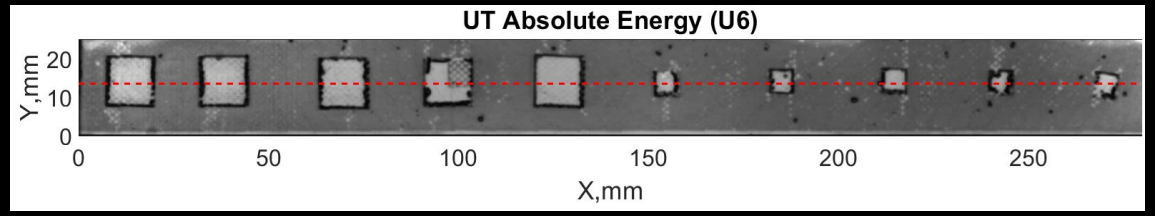

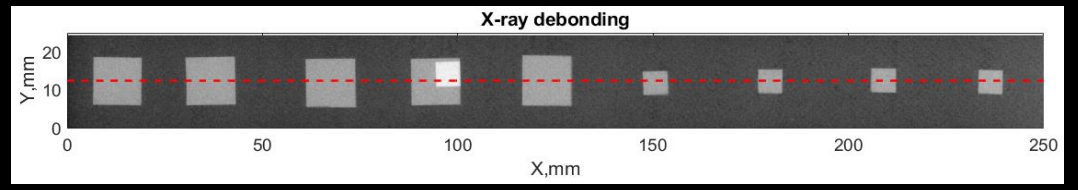

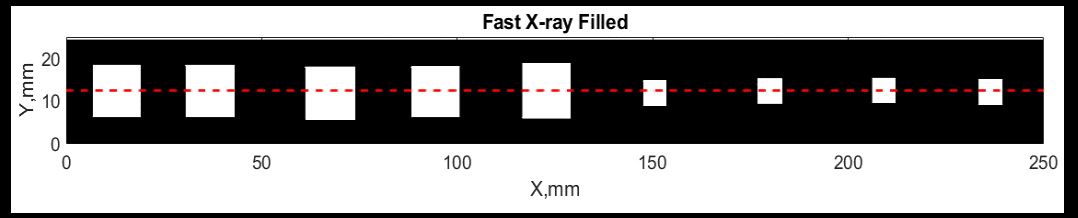

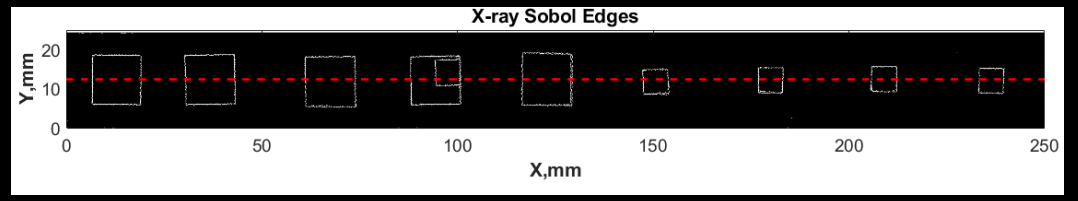

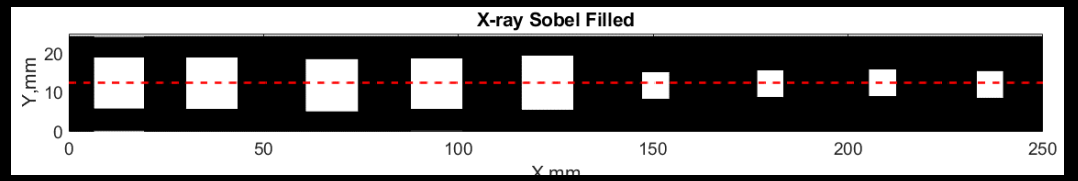

Workflow of data fusion

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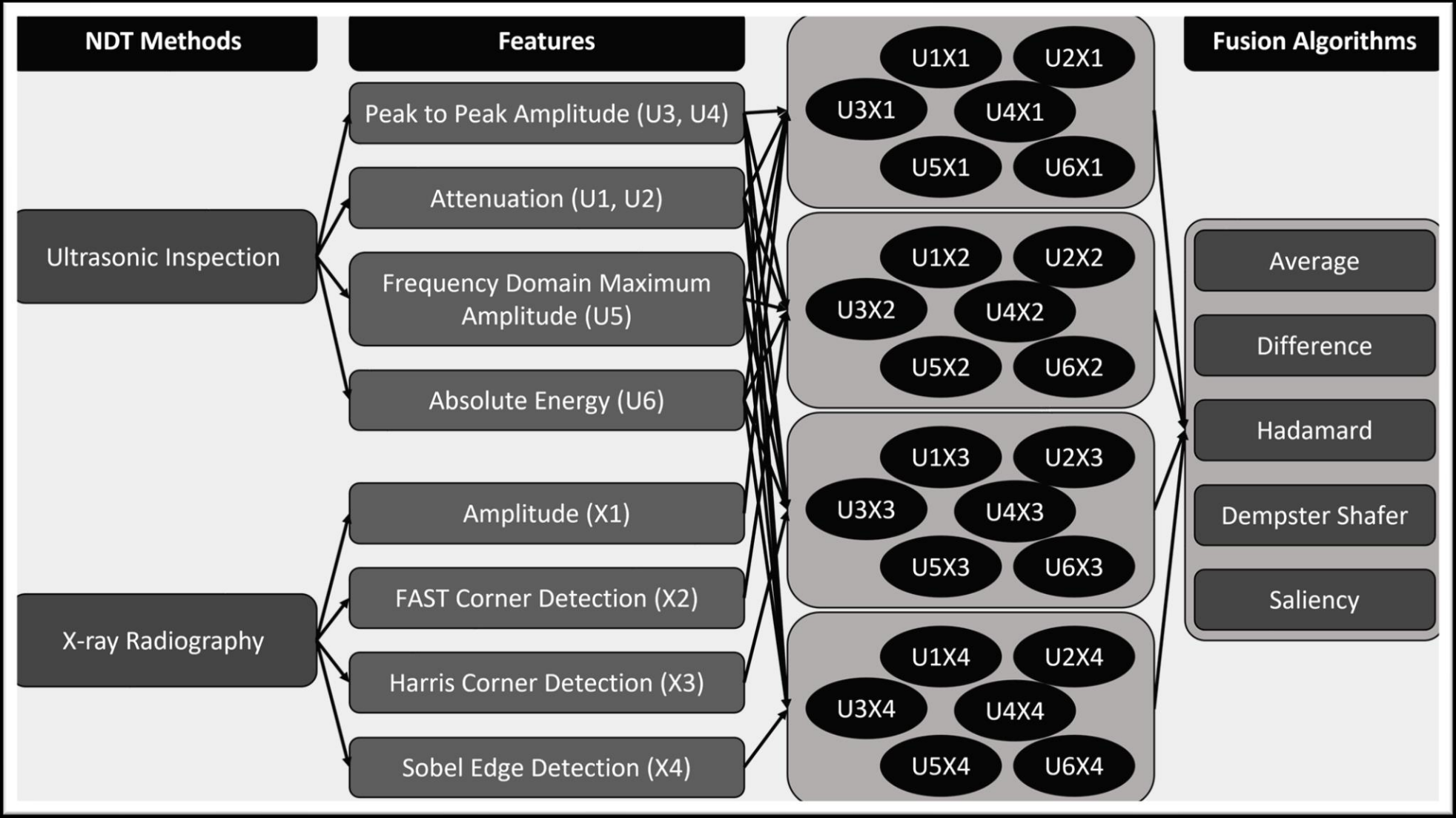

Data fusion

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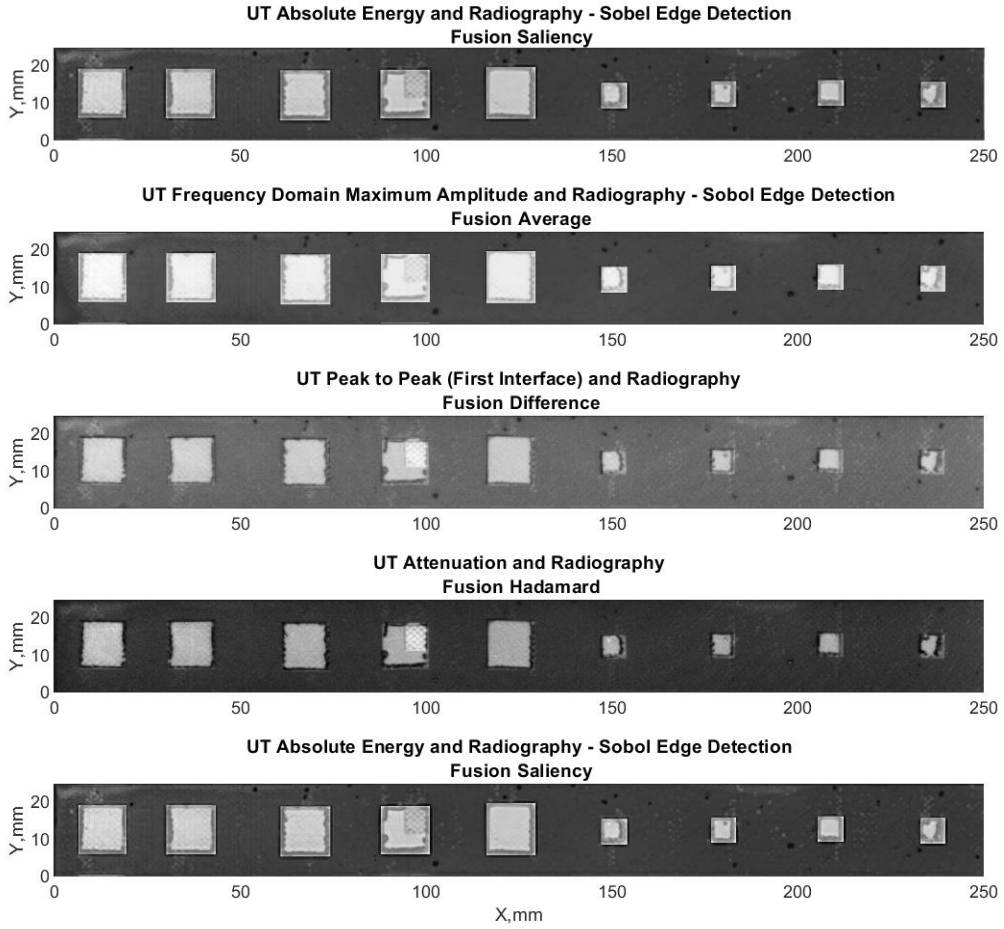

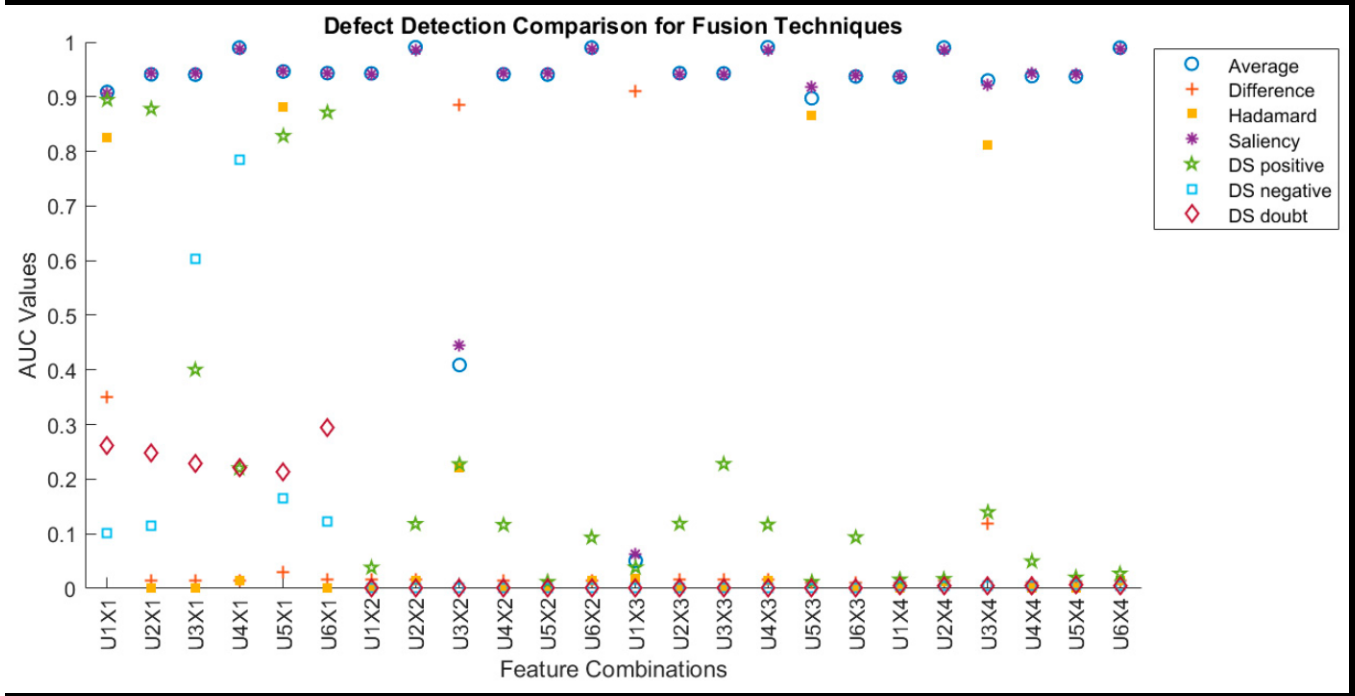

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Conclusions

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- The comparison of extracted features shows that, the most promising UT features are signal attenuation, peak-to-peak amplitude, and absolute energy;
- From RT features amplitude feature performed best;
- Feature-based image fusion helps to overcome the limitations of single techniques, improves the detectability.
- Although radiographic image contributes to the detection of the inclusion type of defect the most, the ultrasonic image provides extra information about additional types of defects, such as disbonds around the edges of the inclusions, which are not visible in the radiographic images.
- The defect detection performance of radiographic features can be improved by the fusion with the best performing ultrasonic features.
- Of the fusion algorithms used, the best performance was achieved using average and saliency algorithms—AUC values of more than 0.99 are achieved

What next

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- Verification of developed algorithms on the evaluation of quality of the weak bonds

Acknowledgment

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Thank you for your attention

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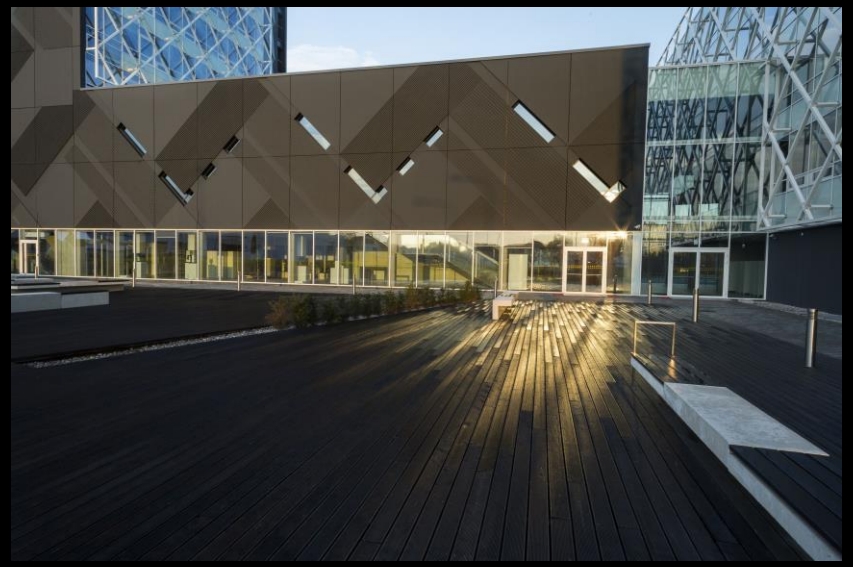

Questions?

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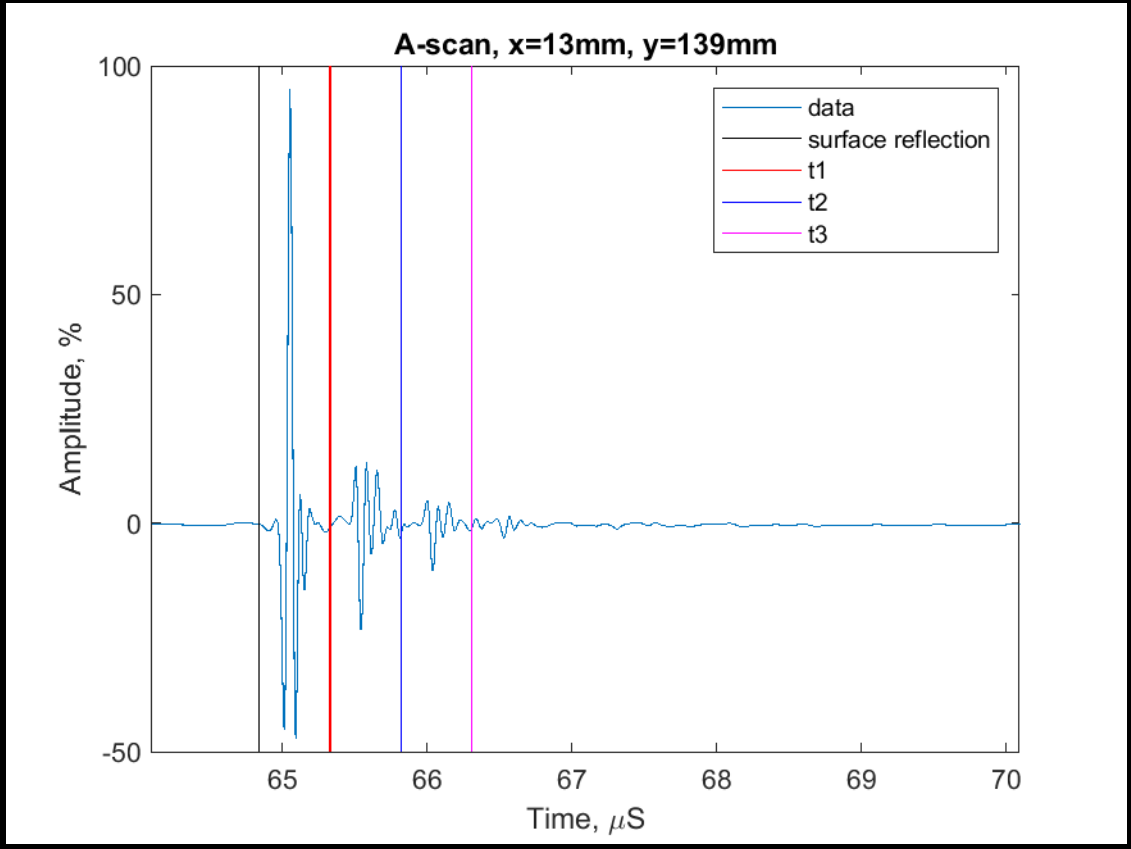
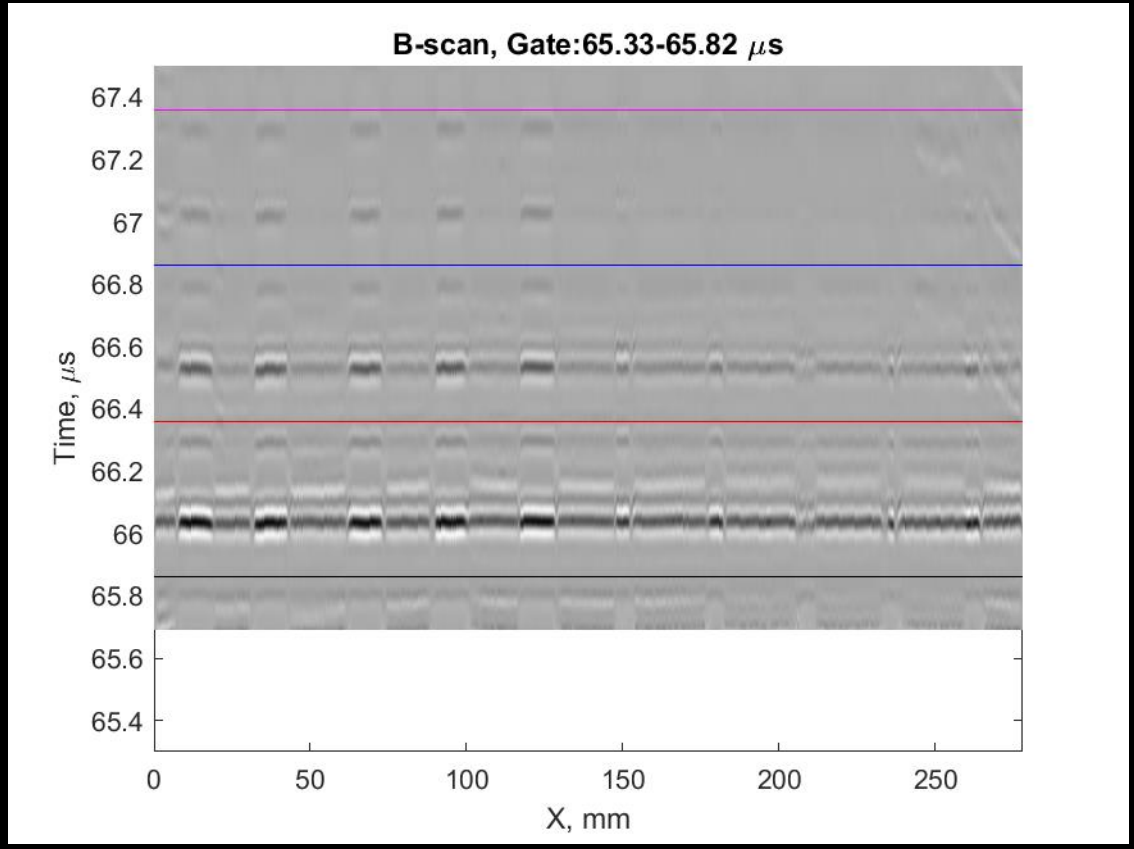
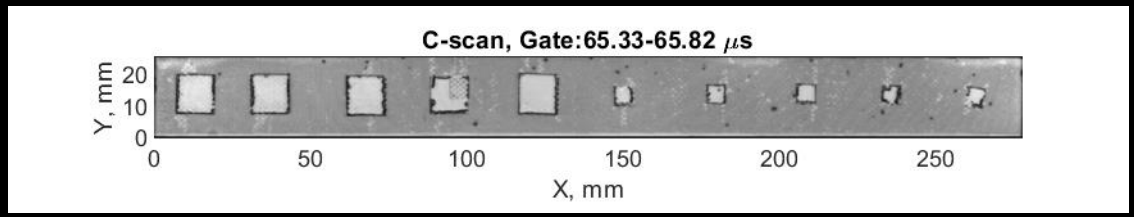
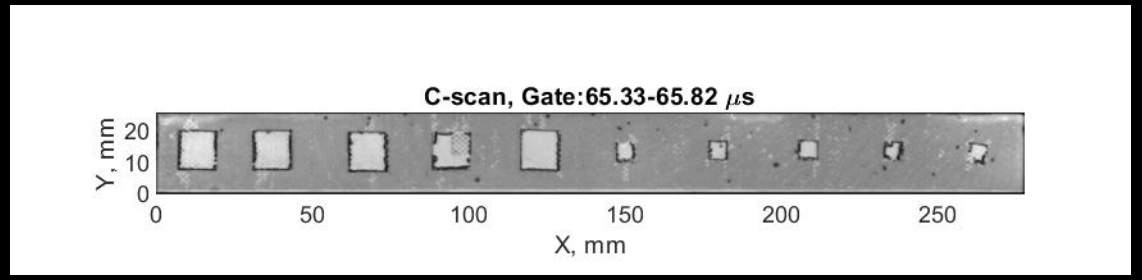
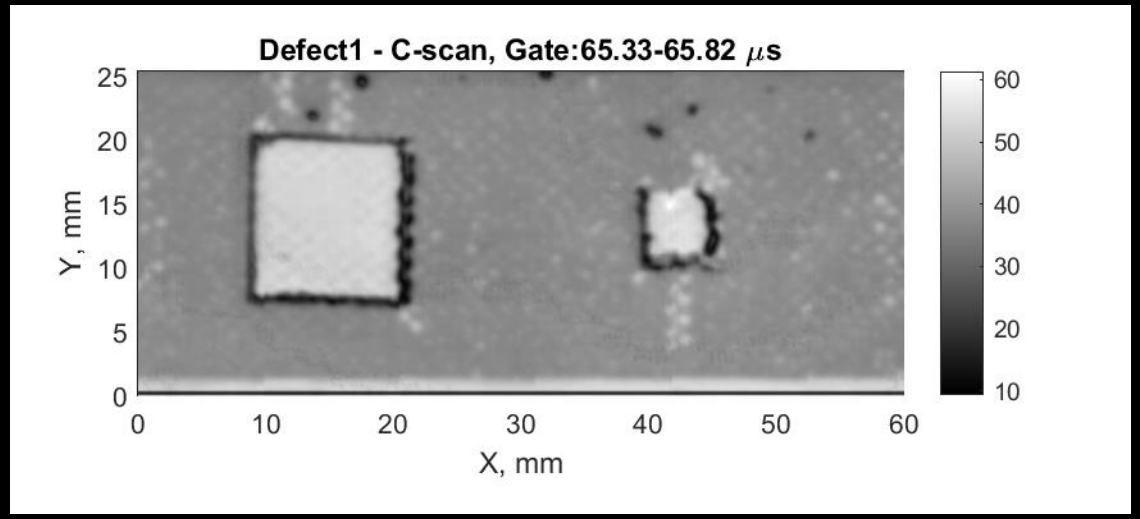

A-scan, x=13mm, y=139mm
data
surface reflection
t1
t2
t3
Amplitude, %
Time, μS
100
50
0
-50
65
66
67
68
69
70


B-scan, Gate:65.33-65.82 μs
Time, μs
X, mm
67.4
67.2
67
66.8
66.6
66.4
66.2
66
65.8
65.6
65.4
0
50
100
150
200
250


C-scan, Gate:65.33-65.82 μs
Y, mm
X, mm
20
10
0
0
50
100
150
200
250


C-scan, Gate:65.33-65.82 μs
Y, mm
20
10
0
0
50
100
150
200
250
X, mm


Defect1 - C-scan, Gate:65.33-65.82 μs
Y, mm
25
20
15
10
5
0
0
10
20
30
40
50
60
X, mm
60
50
40
30
20
10

Multi-dimensional data

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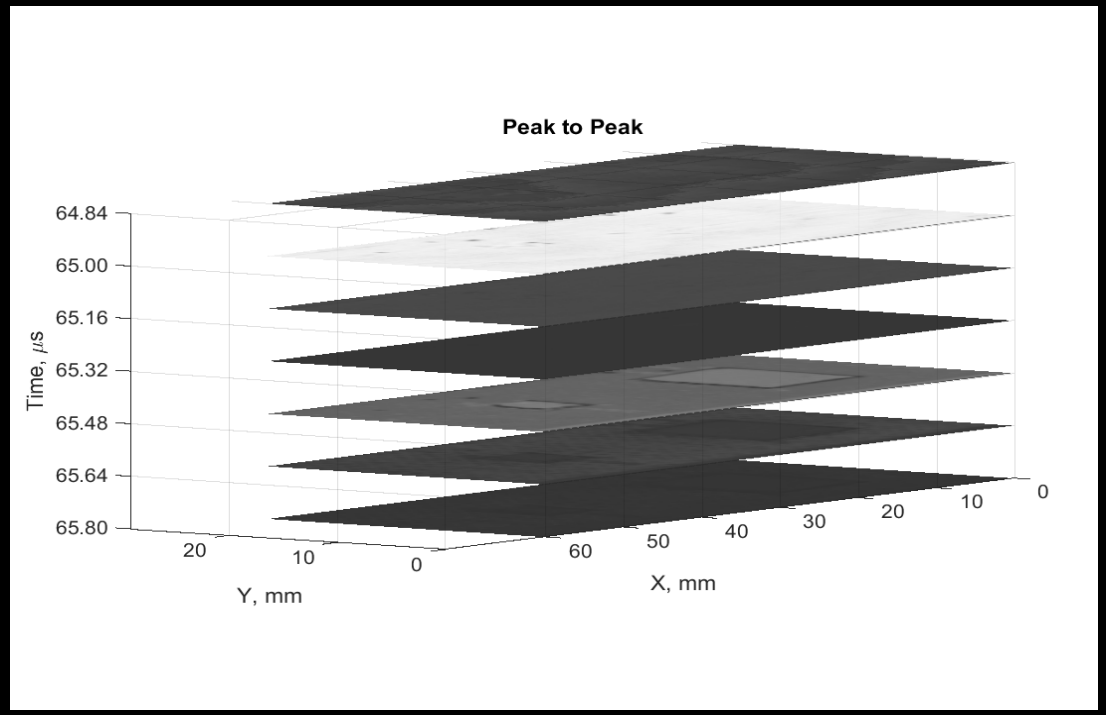
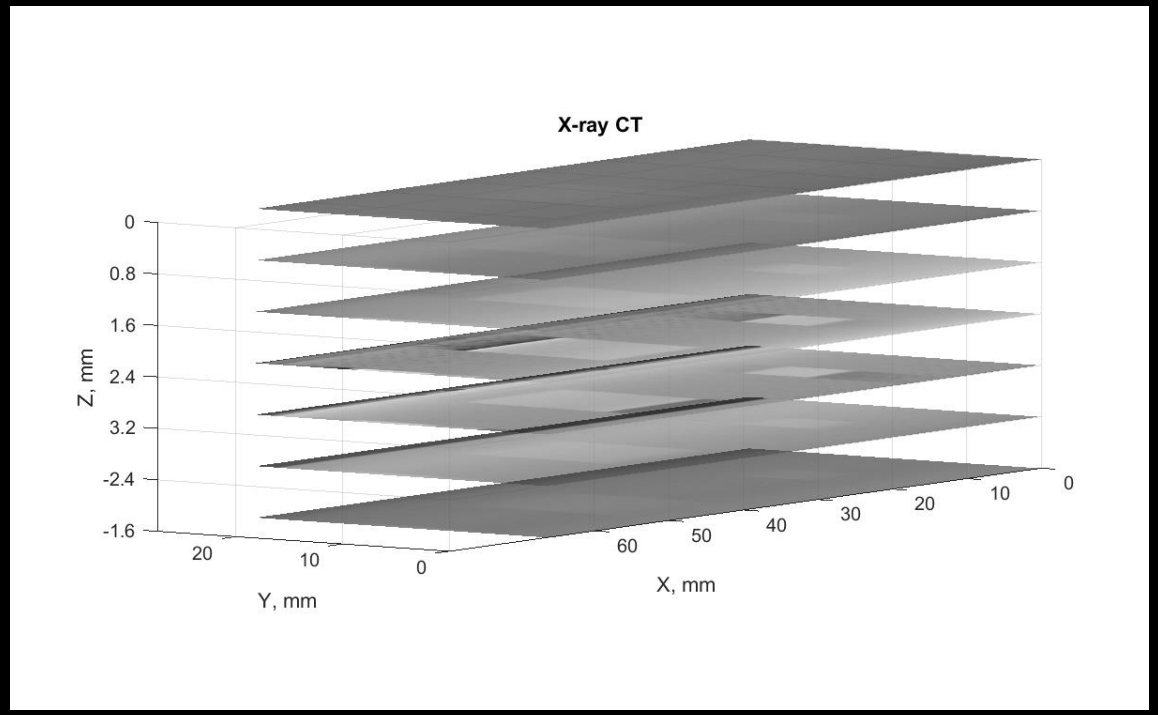
UT



RT



Data Fusion

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Fusion Algorithm	*Description*	*Mathematical formula*
Average	the average of feature matrices from two sources: UT and RT	$\frac{F_{UT} + F_{RT}}{2}$
Difference	the difference of feature matrices from two sources: UT and RT	$F_{UT} - F_{RT}$
Hadamard	multiplication of same-size feature matrices of two sources UT and RT	$(F_{UT} \circ F_{RT})_{ij} = (F_{UT})_{ij}(F_{RT})_{ij}$
Dempster–Shafer	evidence theory based on mass, belief, and plausibility functions	$(m_1 \oplus m_2)(A) = \frac{1}{K-1} \sum_{F_{UT} \cap F_{RT} = A \neq \emptyset} m_1(F_{UT}) m_2(F_{RT})$
Saliency	the salient features are extracted using a basic saliency map detection algorithm	$\chi_m = \lvert \kappa_\eta(p,q) - \kappa_\mu(p,q) \rvert$