Ultrasonic evaluation of friction stir welds and dissimilar intermixing using synthetic aperture focusing technique

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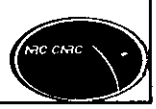
Agenda

- Friction stir welding (FSW)
- SAFT imaging
  - principles
  - improvements
- Results
  - Lap joints, butt joints
  - Dissimilar metal welds
- Comparison with destructive methods



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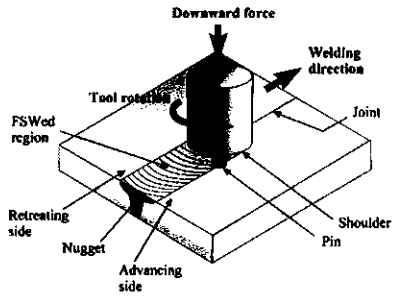
Friction stir welding

- Manufacturing of aircraft panels
- Rivet replacement: saving of weight, productivity and aerodynamics
- Some challenges: hooking, lack of penetration, wormholes, kissing bond



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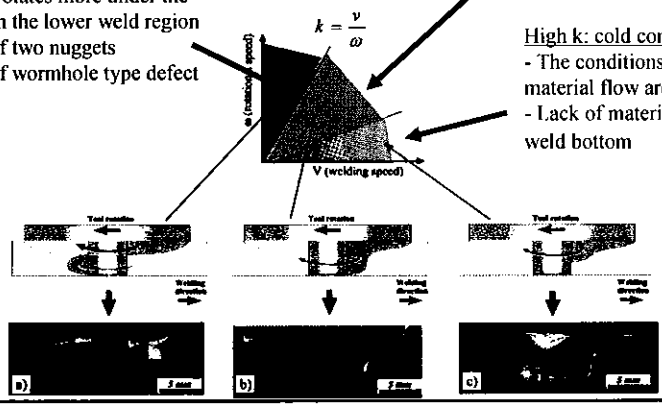
Material flow

Low k: hot condition (overstirring)
- High heat generation and stirring under the shoulder
- The material rotates more under the shoulder than in the lower weld region
- Appearance of two nuggets
- Appearance of wormhole type defect

Intermediate k: stable condition
- The flow of the boundary layer is stable
- Sound and defect-free weld

High k: cold condition
- The conditions for stable material flow are not reached
- Lack of material feeding in the weld bottom



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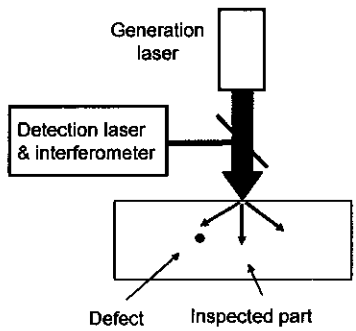
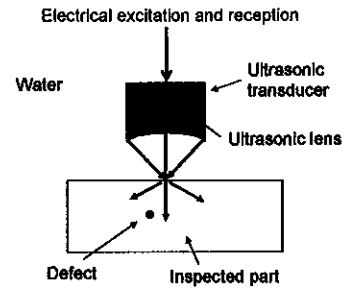
Synthetic aperture focusing technique (SAFT)

- Source of ultrasound and detection zone overlap at the surface of the part
- Laser-ultrasonics or conventional piezoelectric transducer focused on the surface
- Mechanical scanning along two axis (can also use a transducer array for one or two-axis scan)
- Numerical acquisition of all the A-scans





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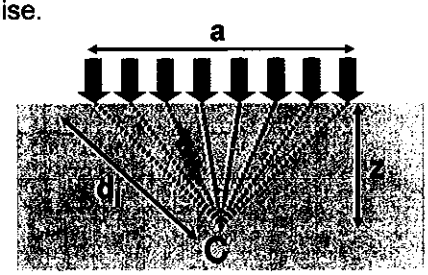
Time domain SAFT

- For any point C in the volume:
  1- Locate the amplitude of each signal at time $2d_i/v$
  2- Sum the contributions in the aperture a
- Large amplitude obtained if a flaw is located at C; otherwise, a reduction of noise.



- In practice, computation in the Fourier domain: F-SAFT

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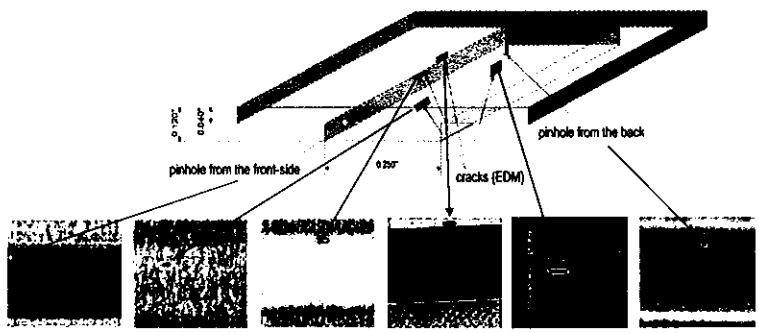
Sample with artificial defects



Thickness: 3 mm
Pin holes: 0.5 mm dia; EDM slots: 0.175 mm width

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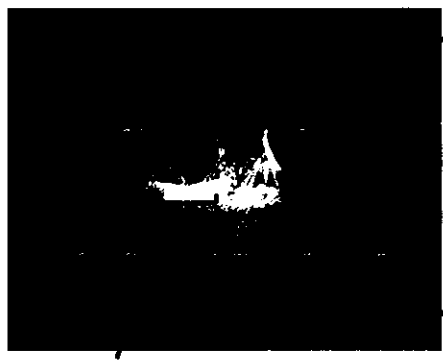
FSW lap joint

- Al sample, 4 mm thick



Defect: large hooking on AS

7075 1,5-mm plate

2024 2,5-mm plate

Defect: wormhole

Defect: kissing-bond on RS

RS: retreating side
AS: advancing side

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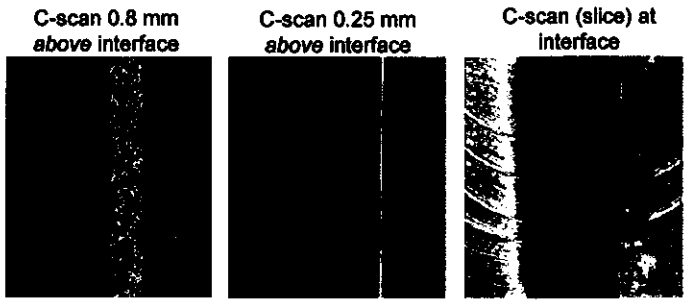
SAFT results: tool side



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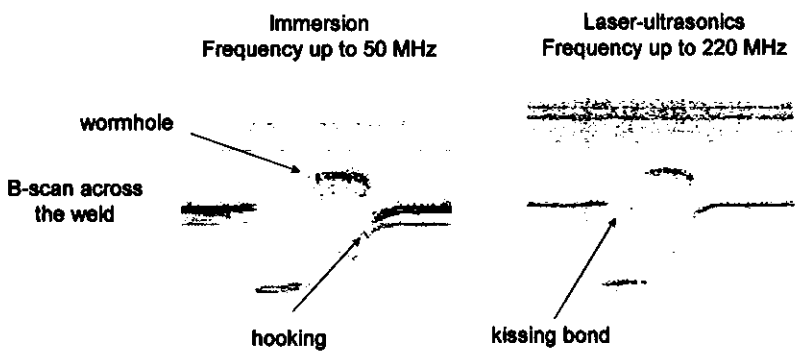
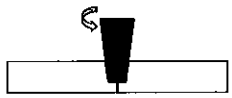
SAFT results: opposite side



FSW butt joint

- Al sample, 2 mm thick



LOP height: 600 μm
LOP width: 10 μm

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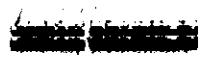
SAFT results: tool side

C-scan (slice)
near bottom face

Lack of
penetration

B-scan across
the weld



Backwall

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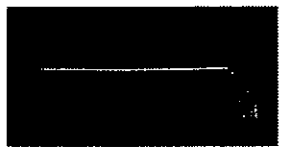
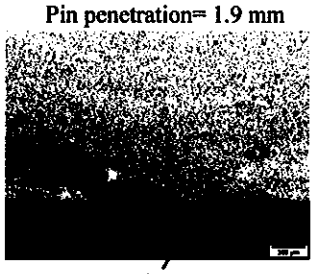
Sample with variable pin length

Al sample
2.56 mm thick (0.1 inch)

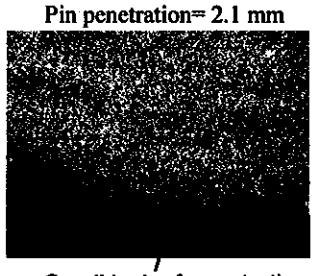


Pin penetration= 1.9 mm



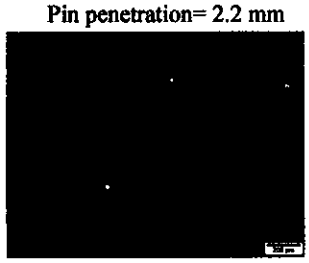
Lack of penetration

Pin penetration= 2.1 mm



Small lack of penetration

Pin penetration= 2.2 mm



Full penetration

➢ No visible defect for a pin penetration ≥ 2.2 mm

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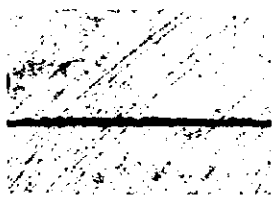
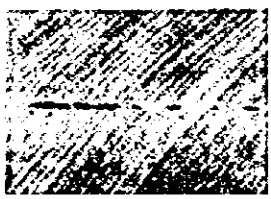
SAFT results: tool side

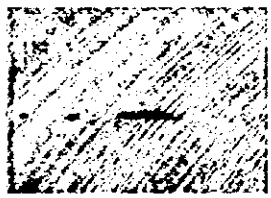
1.4 mm

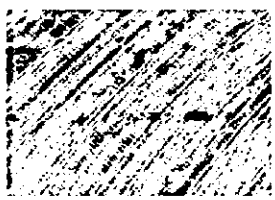


1.6 mm



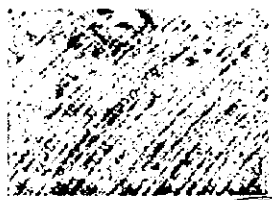
1.8 mm





2.0 mm

2.1 mm



2.2 mm

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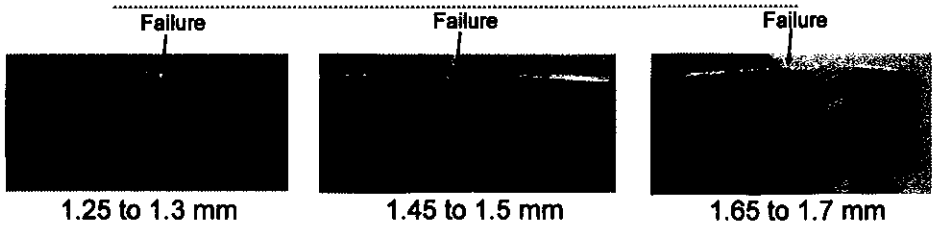
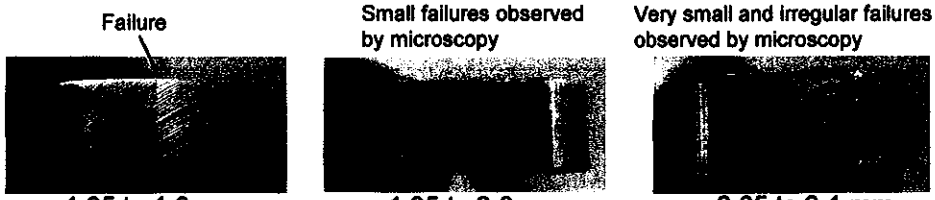
Bend test results



1.25 to 1.3 mm | 1.45 to 1.5 mm | 1.65 to 1.7 mm



1.85 to 1.9 mm | 1.95 to 2.0 mm | 2.05 to 2.1 mm

➢ No failure for a pin penetration ≥ 2.14 mm

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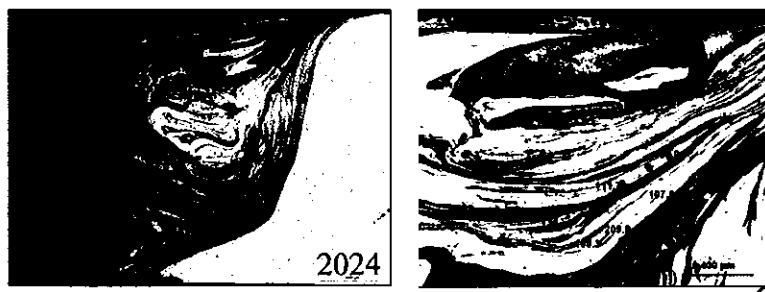
Dissimilar FSW welds

- Determination of process parameters for FSW of butt joints Mg AZ31 and Al 2024.
- Complex vortex flow characterized by intercalated lamellar structure.
- High hardness probably due to the formation of $Al_{12}Mg_{17}$.
- Low hardness probably due to loose structure.



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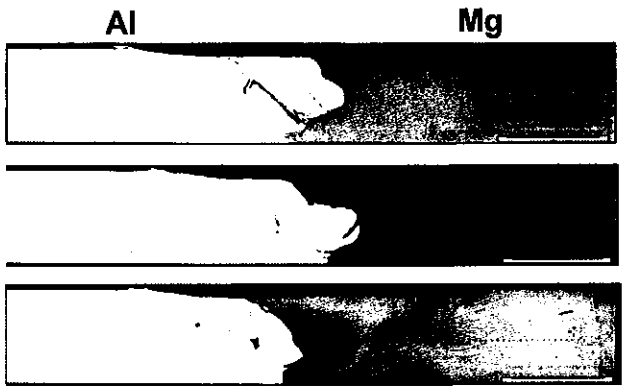
Effect of welding speed



Rotational speed: 250 RPM
Thickness: 5 mm

V ↓ , T ↑, intermetallic ↑

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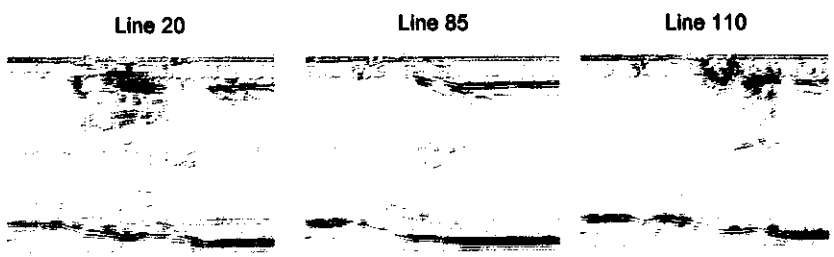
Measurement: tool side

- B-scan



Al (left) - Mg (right)

Scan: 10 mm wide, 20 mm along weld axis

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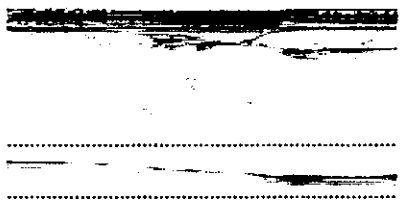
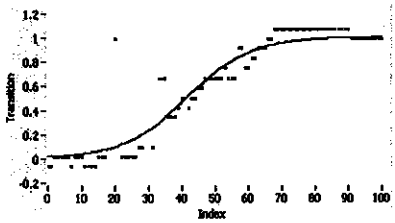
SAFT: improvements

B-scan:
Butt joint, 5 mm thick



Transition:
Fit of the bottom echo



Al (left)
6.4 mm/us

Mg (right)
5.8 mm/us

This information from the backwall echo is used in the SAFT reconstruction

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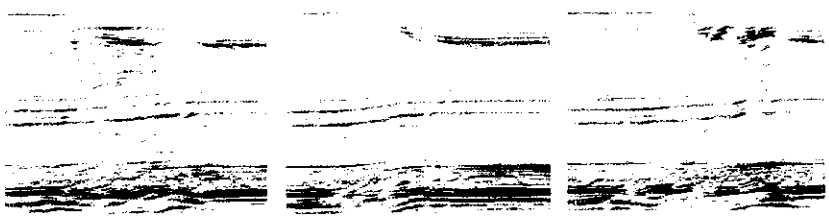
SAFT results

- B-scan

Line 20 Line 85 Line 110



Al (left) - Mg (right)

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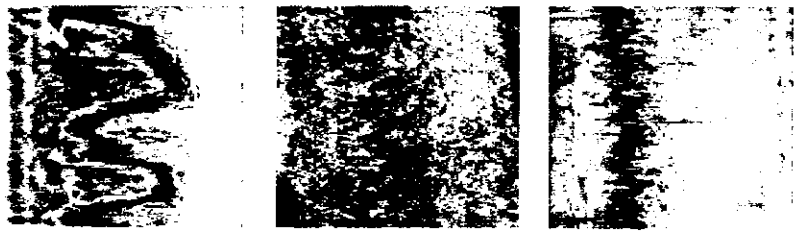
SAFT results: mid-plane

- C-scan

0.75 mm/s | 9.0 mm/s | 15.0 mm/s



Al (left) - Mg (right)

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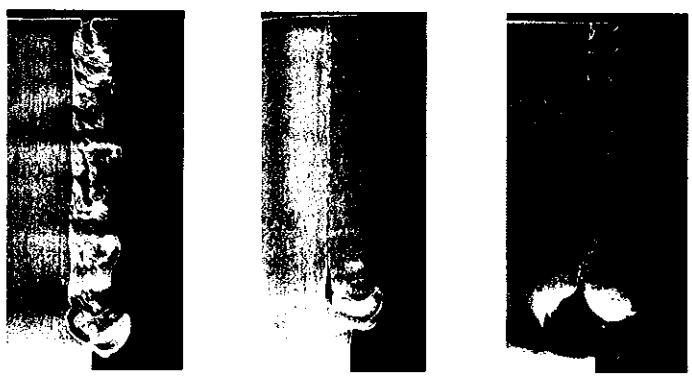
Testing by Micro-CT

- Front views, mid-plane

0.75 mm/s | 9.0 mm/s | 15.0 mm/s



References

1. D. Kleiner and C.R. Bird, "Signal processing for quality assurance in friction stir welds", Insight, Vol. 46, pp. 85-87, 2004.
2. S. Iwaki et al., Imperfections in friction stir welded zones and their precision non-destructive testing. Studies on characteristics of friction stir welded joints in structural thin aluminium alloys, Welding Intern. 20, pp. 197-205, 2006.
3. D. Lévesque, A. Blouin, C. Néron and J.-P. Monchalin, Performance of laser-ultrasonic F-SAFT imaging, Ultrasonics 40, pp. 1057-1063, 2002.
4. D. Lévesque et al., "Synthetic aperture focusing technique for the ultrasonic evaluation of friction stir welds", Review of Progress in Quantitative NDE Vol. 27, ed. by D.O. Thompson and D.E. Chimenti, AIP, New York, pp. 263-270, 2008.

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Thank You!