High-temperature TOFD trial

Time-of-flight diffraction on carbon steel welded plate at up to 240 °C

1. Scope of the Technical Note

Ultrasonic time-of-flight diffraction (TOFD) is a popular method widely used in petrochemical, energy and other industries for the in-service detection and characterisation of welds defects such as root corrosion, porosity, inclusions, and cracks. However, with increasing demand for on-stream measurements, conventional TOFD is limited due to the temperature at which these probes can operate, often causing failure of the transducer, or causing noise in the wedges to mask the ultrasound signal. A demonstration of the Ionix high-temperature TOFD transducers, with integrated wedges, for their suitability for weld inspection at elevated temperatures up to 240 °C is shown here. The wedges are mounted on to a modified EddyFi Lyncs scanner for high-temperature encoding, with high-temperature couplant, connected to commercially available UT sets from EddyFi and Olympus.

Highlights:

- All noted indications are identifiable through the temperature range 15 to 240 °C
- Acceptable sensitivity to defect detection maintained independent of UT set
- Suitable resolution was maintained for signal separation at elevated temperature

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2. Methodology

Two carbon steel test blocks with manufactured defects were chosen for evaluation from Sonaspection, summarised in Table 1 (see Appendix A for more information).

Table 1: Summary of the test blocks used for evaluation

Test block i.d.	Material	Thickness	Number of weld defects
001	Carbon steel	30 mm	2
002	Carbon steel	28 mm	4

An EddyFi Lyncs scanner was modified with magnetic wheels, compatible tool posts and encoder for high-temperature operation (up to 350 °C). The encoder compatible with both the Olympus Omniscan X3 and EddyFi Mantis UT sets used.

A pair of Ionix HotSense, 5 MHz, 6mm diameter crystal HT TOFD probes with integrated 60 degree (at 200 °C, see Appendix B) non-profiled (flat) wedges were fitted with compatible pins for the Lyncs HT scanner, and coupled with Echo Ultrasonics Echo 6HT pumpable couplant (with an auto-ignition temperature of 421 °C) through the couplant channels on a continuous drip feed from a hand pump.

The probes were connected to the UT set via 5 m, dual lemo 00 to lemo 00 high-temperature cables.

An initial benchmark with water as couplant at ambient temperature was taken on test block 001, using the EddyFi Mantis prior to being placed on the setup at Iris NDT.

Post-weld heat treatment (PWHT) ceramic mat heaters were placed on a bed of insulation, and the test blocks placed on top of the heaters with a K-type thermocouple affixed with putty to the underside of each test block. The heaters were connected to PWHT power unit and the temperature monitored by thermocouple, and infrared thermometer on the top surface to ensure uniformity through the test block within 20 °C before a measurement is made.

A-scan range was set capturing the lateral wave, backwall reflection and mode converted wave on each block on a section without flaws, from a PCS calculated for the wedge used, at ambient temperature. No compensation was made for elevated temperature on the PCS (due to the angle change) or velocity.

The pulser voltage used was the default for TOFD on each system, nominally 200 V (Mantis, EddyFi) and 300 V (Olympus X3) with a 100 ns pulse length. Receiver filters used were low pass 10 MHz (Mantis), and bandpass around 5 MHz (Omniscan).

A set of benchmarks were taken for test block 001 and 002 connected to each of the EddyFi Mantis and Olympus X3 when in place at Iris NDT on the heat mat, using Echo 6HT at ambient temperature.

B-scans were produced for test block 002, scanning the length of the welds, capturing data in 1 mm steps.

B-scan measurements were taken at surface temperature setpoints of ambient (~15), 200 and 250 °C.

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Figure 1: *Photograph of the evaluation setup at Iris NDT (Immingham, UK)*

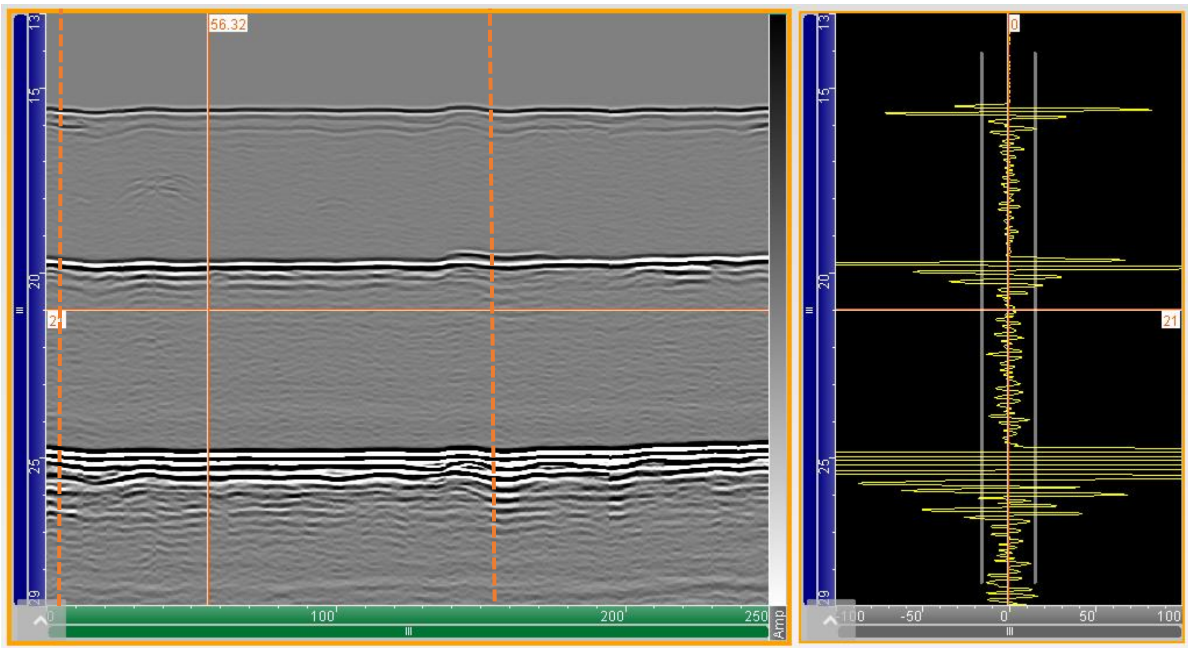

Figure 2: *Mantis B-scan (left) and A-scan (right) representation collected with 5 MHz, 6 mm dia transducers with 60-degree integrated wedge from a test block 001, at a surface temperature of 19 °C and water couplant. A PCS of 67 mm was used with a reference gain of 20 dB. Defects are highlighted with an orange dashed line (solid for reference to A-scan)*

3. Results

3.1. Test block 001

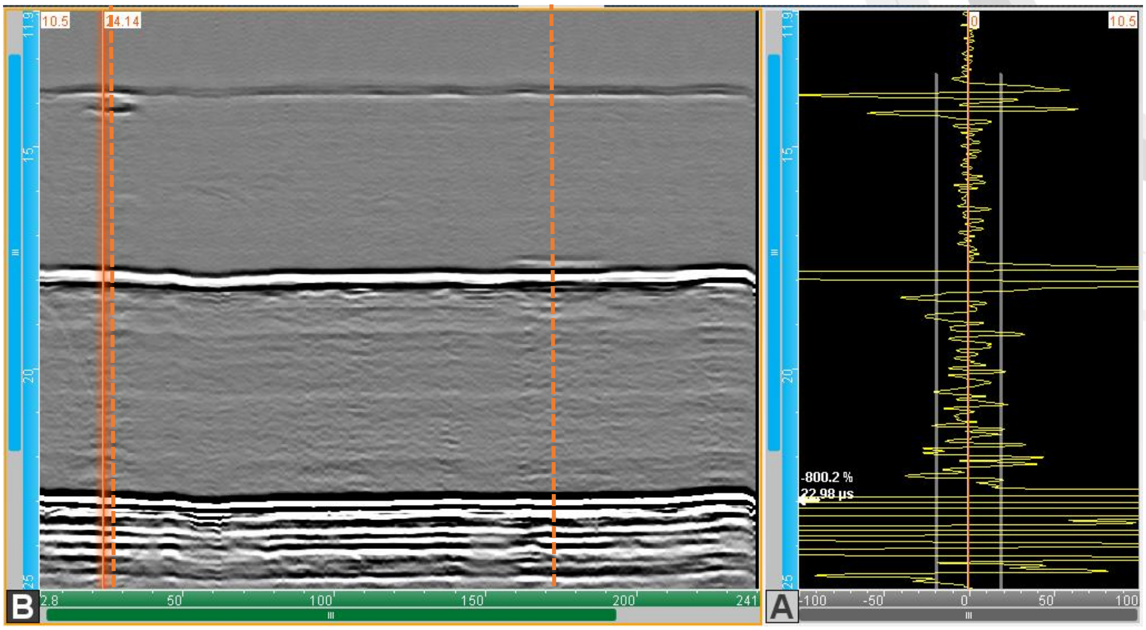

Figure 3: *Mantis B-scan (left) and A-scan (right) representation collected with 5 MHz, 6 mm dia transducers with 60-degree integrated wedge from a test block 001, at a surface temperature of 15 °C with Echo6HT couplant. A PCS of 57 mm was used with a reference gain of 33 dB. Note the scan is taken in opposing direction to Figure 2. Defects are highlighted with an orange dashed line.*

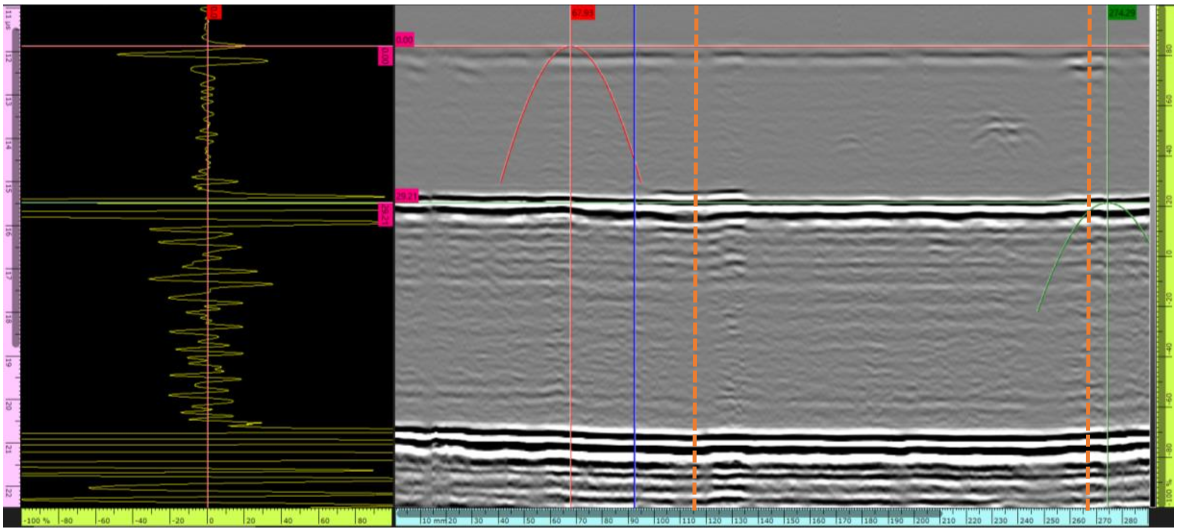

Figure 4: *Omniscan X3 B-scan (right) and A-scan (left) representation collected with 5 MHz, 6 mm dia transducers with 60-degree integrated wedge from a test block 001, at a surface temperature of 15 °C with Echo6HT couplant. A PCS of 57 mm was used with a reference gain of 77 dB. Note the scan is taken in opposing direction to Figure 3. Defects are highlighted with an orange dashed line.*

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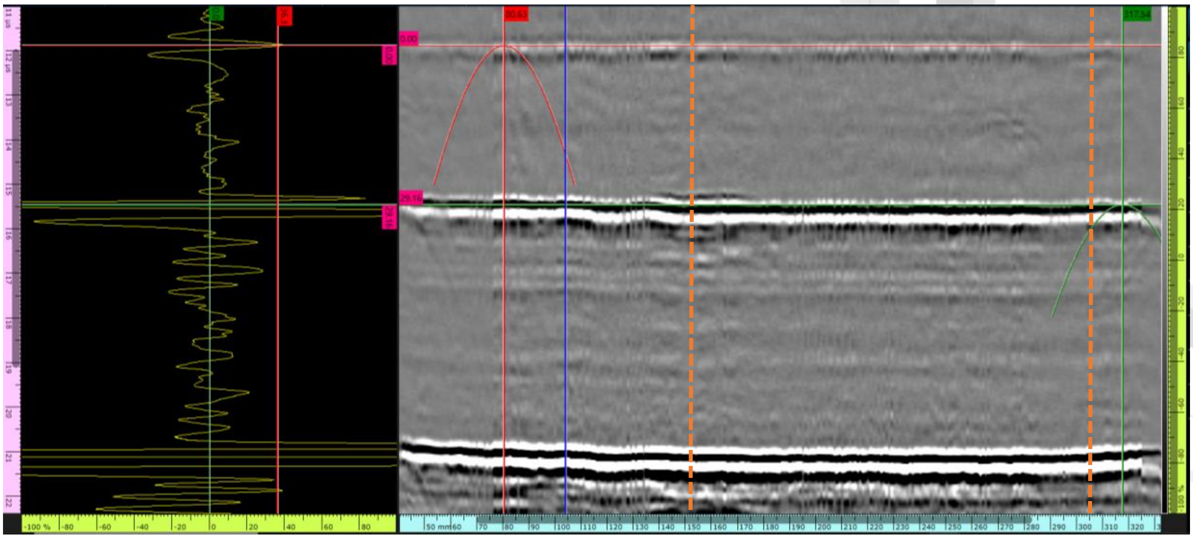

Figure 5: *Omniscan X3 B-scan (right) and A-scan (left) representation collected with 5 MHz, 6 mm dia transducers with 60-degree integrated wedge from a test block 001, at a surface temperature of 200 °C with Echo6HT couplant. A PCS of 57 mm was used with a reference gain of 81 dB. Note the scan is taken in opposing direction to Figure 2. Defects are highlighted with an orange dashed line.*

Two defects in test block 001 (a weld cap crack and root crack) are detected with excellent SNR and sensitivity in Figure 2. The same defects are seen in Figures 3 and 4 with both UT sets, albeit with a sensitivity reduction when switching to the high temperature pumpable couplant instead of water. On heating to 200 °C (Figure 5) the gain is increased by 4 dB to compensate for the increased attenuation in the steel. The two defects are still clearly seen.

3.2. Test block 002

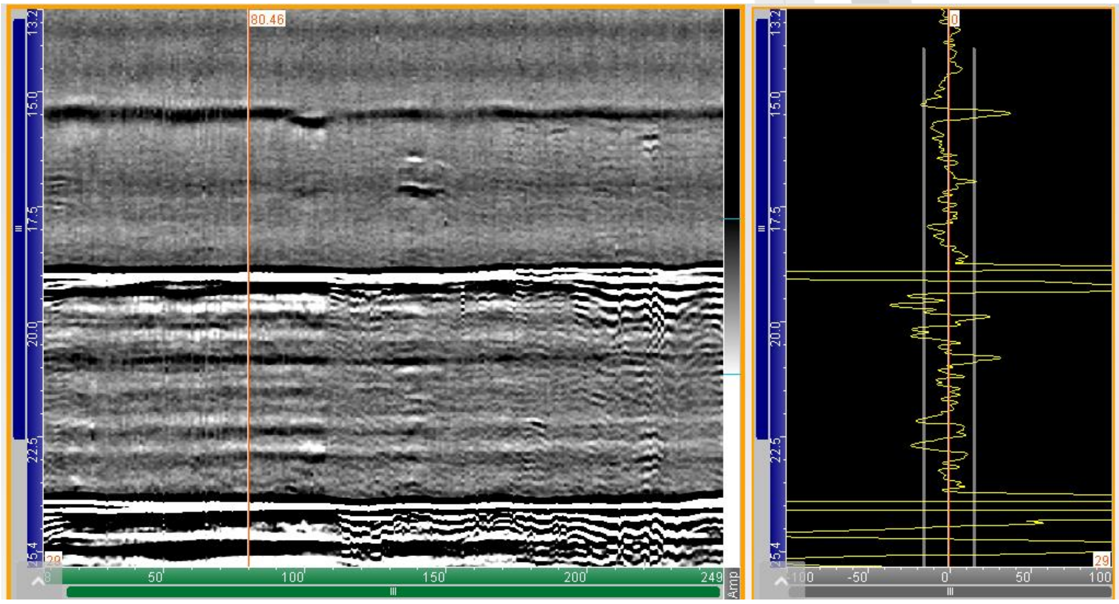

Figure 6: *Mantis B-scan (left) and A-scan (right) representation collected with 5 MHz, 6 mm dia. transducers with 60-degree integrated wedge from a test block 002, at a surface temperature of ~15 °C with Echo6HT couplant. on heating. Reference gain of 40 dB.*

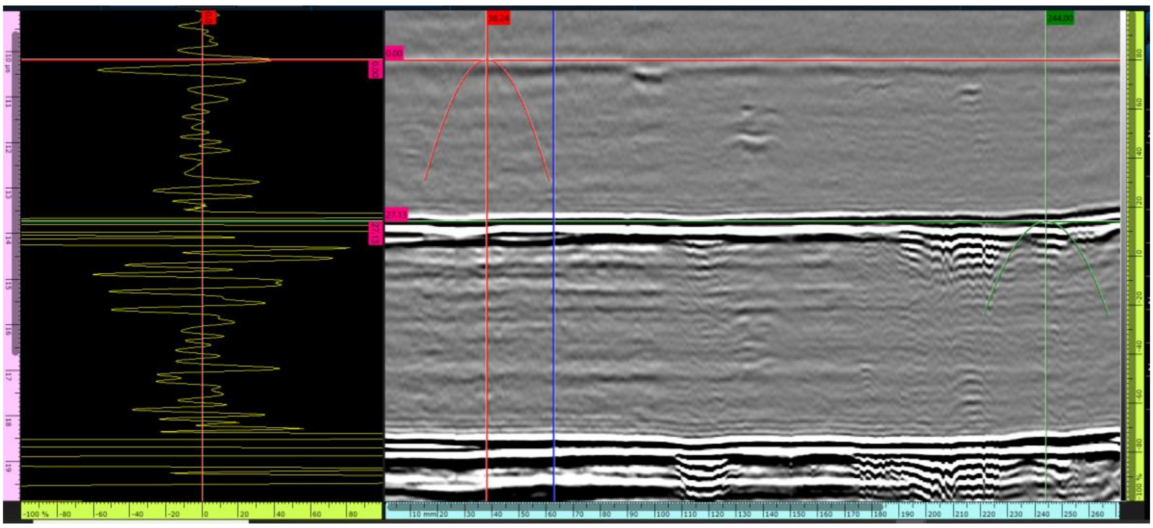

Figure 7: *Omniscan X3 B-scan (right) and A-scan (left) representation collected with 5 MHz, 6 mm dia. transducers with 60-degree integrated wedge from a test block 002, at a surface temperature of ~120 °C (on ramp up heating from ambient to 200 °C setpoint) with Echo6HT couplant. Reference gain of 86 dB.*

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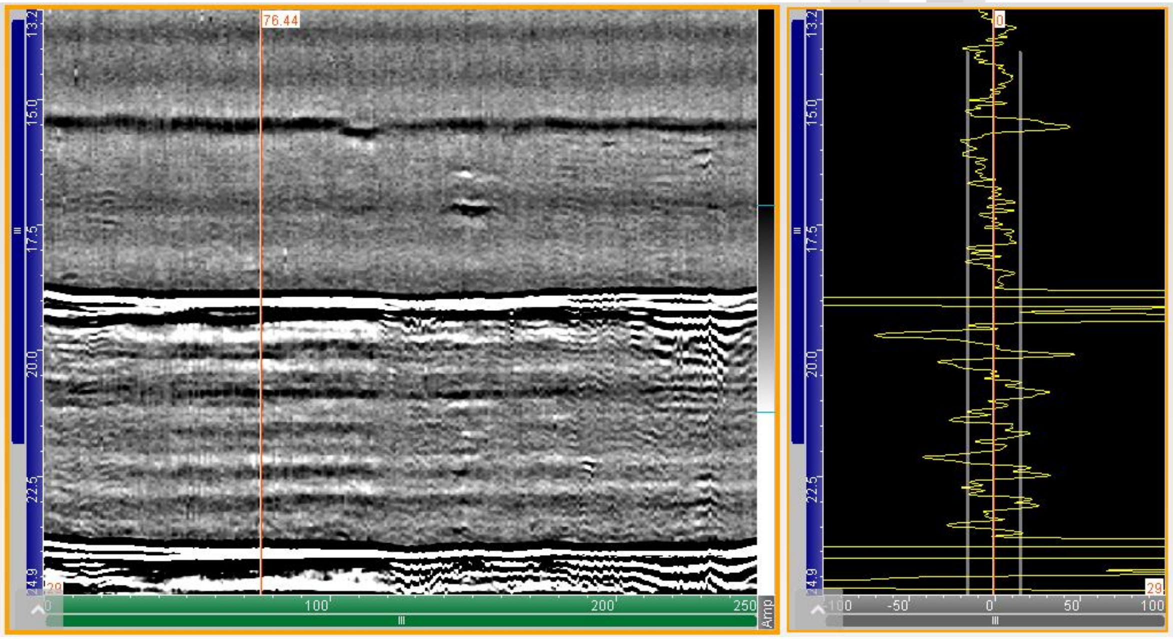

Figure 8: *Mantis B-scan (left) and A-scan (right) representation collected with 5 MHz, 6 mm dia. transducers with 60-degree integrated wedge from a test block 002, at a surface temperature of 190 °C with Echo6HT couplant. Reference gain of 54 dB.*

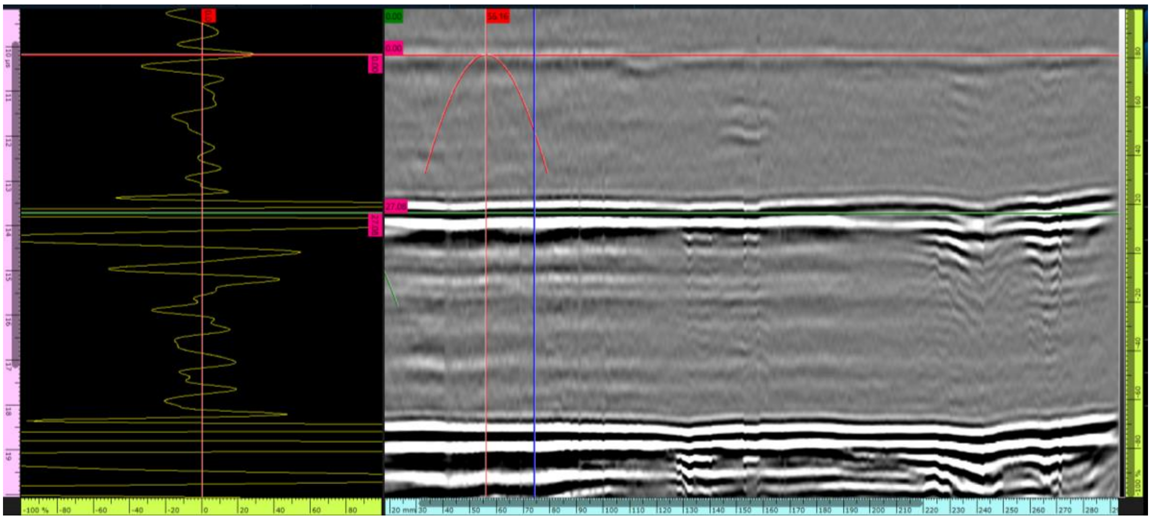

Figure 9: *Omniscan X3 B-scan (right) and A-scan (left) representation collected with 5 MHz, 6 mm dia. transducers with 60-degree integrated wedge from a test block 002, at a surface temperature of 190 °C with Echo6HT couplant. Reference gain of 91 dB.*

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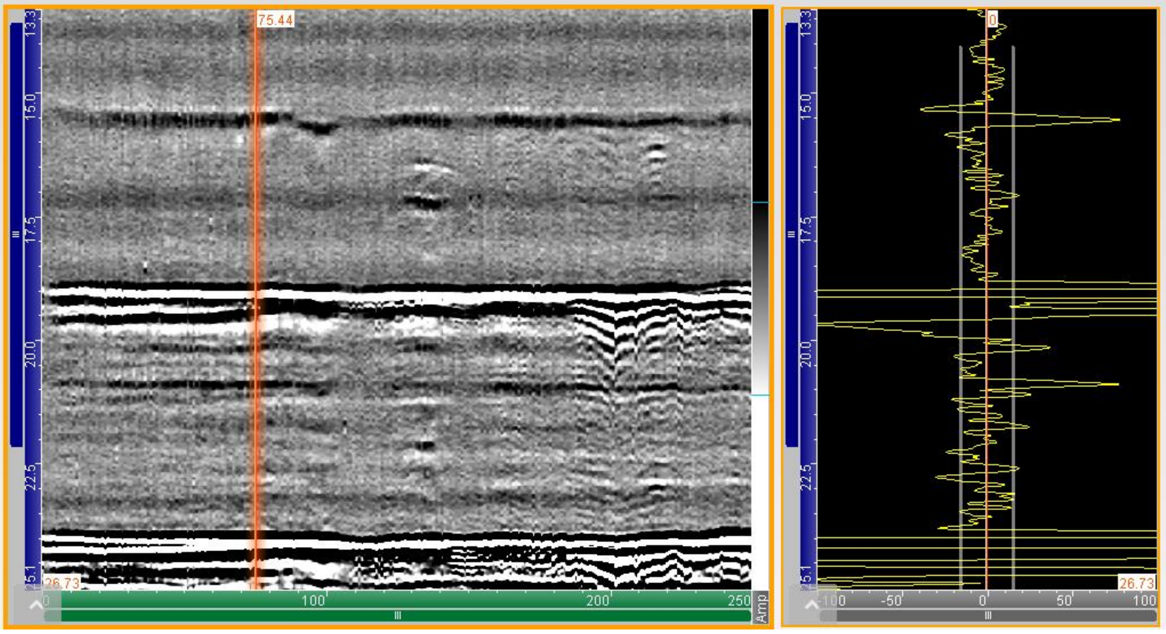

Figure 10: *Mantis B-scan (left) and A-scan (right) representation collected with 5 MHz, 6 mm dia. transducers with 60-degree integrated wedge from a test block 002, at a surface temperature of 240 °C with Echo6HT couplant. Reference gain of 54 dB.*

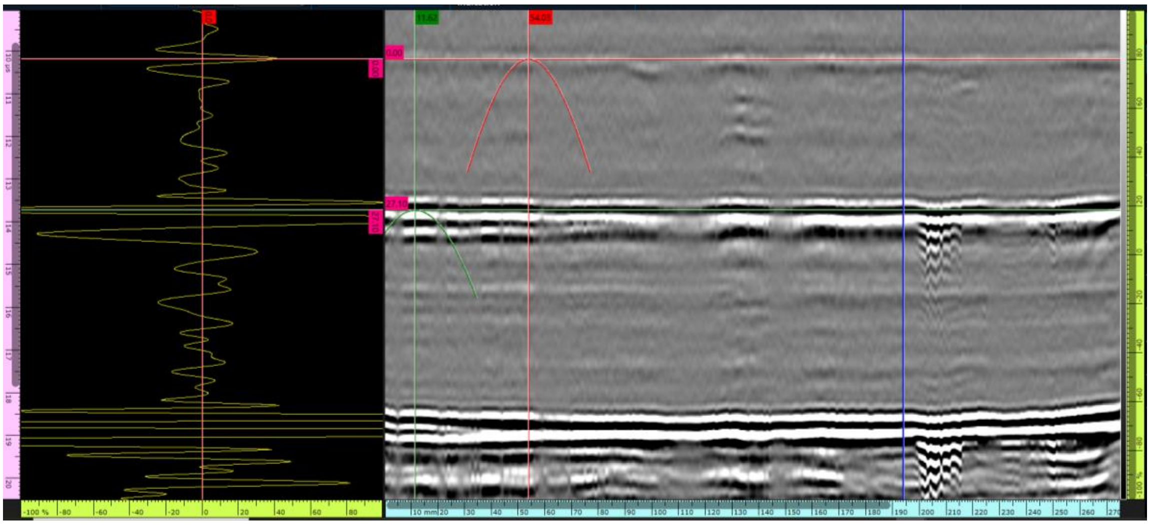

Figure 11: *Omniscan X3 B-scan (right) and A-scan (left) representation collected with 5 MHz, 6 mm dia. transducers with 60 -egree integrated wedge from a test block 002, at a surface temperature of 240 °C with Echo6HT couplant. Reference gain of 91 dB.*

All four defects in test block 002 (see Appendix A) are detected with good SNR and sensitivity in Figure 6 and 7 at ambient temperature with high-temperature couplant. The same defects are seen in Figures 8 and 9 at a stable surface temperature of 190 °C with both UT sets with a reasonable increase in gain to offset the

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attenuation of the steel. The four defects are still clearly seen in both sets, and is repeated with similar results at the final temperature of 240 °C.

4. Conclusions

Throughout the temperature range, 15 to 240 °C;

- All noted indications are identifiable
- Acceptable sensitivity to defect detection
- Suitable resolution was achieved for signal separation

HotSense Technical Note	
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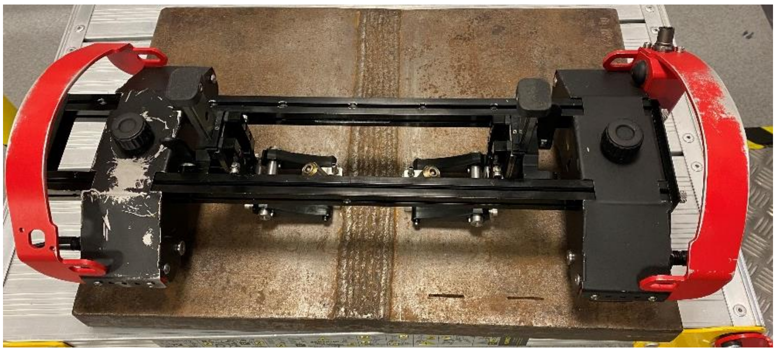
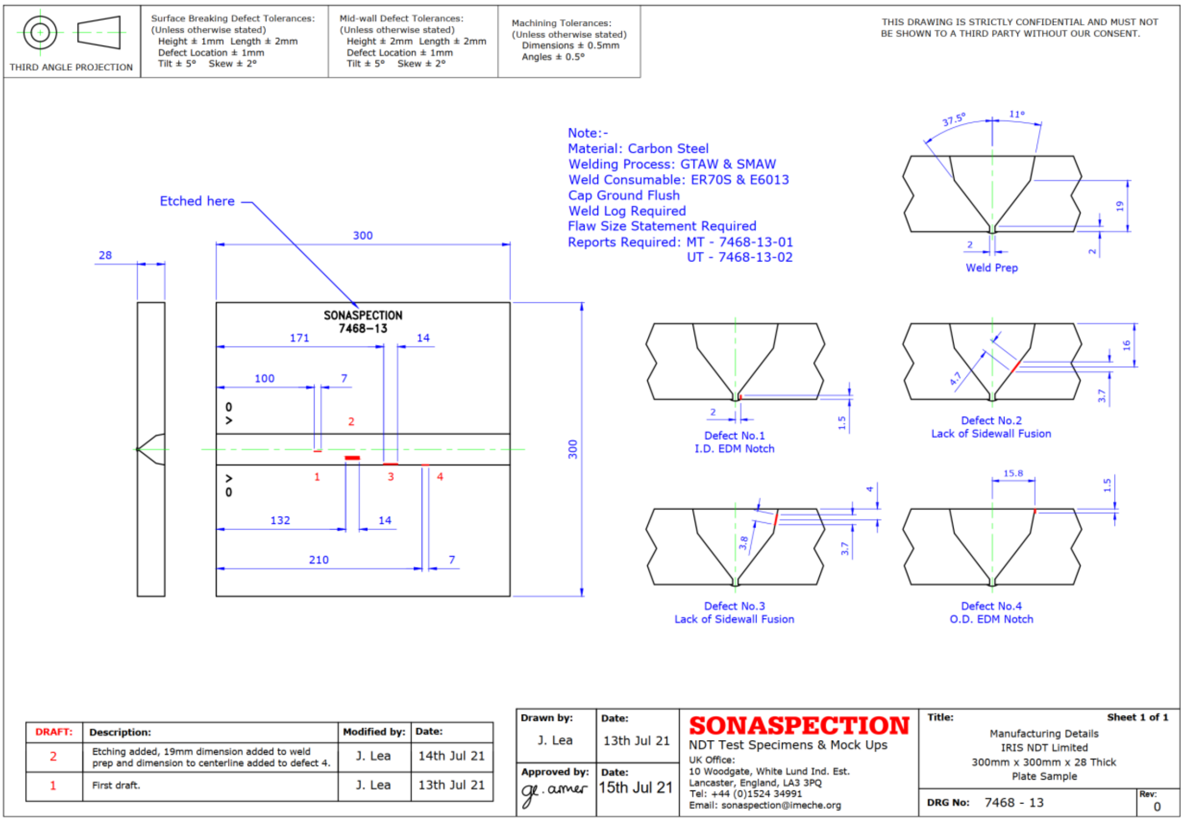
5. Appendix A – Test block description

Test block 001 – C1-1249

Test block i.d.	Material	Thickness	Geometry	Defects
001	Carbon steel	30 mm	450 x 300 mm weld cap 40 mm wide	1 root crack 1 weld cap crack



Test block 002 – serial # 7468-13



6. Appendix B - Refracted beam angle as a function of temperature

Due to the change in velocity of both the transducer wedge and carbon steel test piece, Snell's law determines the refracted angle of the longitudinal beam will increase with increasing temperature as shown by the plot below.

Ionix HotSense TOFD wedges nomenclature reference the wedge angle at 200 °C, with the chart below used to determine the actual refracted angle more accurately at temperatures above and below.