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Phased Array Ultrasonic Inspection Of 25% Cr Super Duplex Stainless Steel On Subsea Manifold Piping Girth Welds In Lieu Of Radiography

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Abstract. 25%Cr super duplex stainless steel volumetric weld inspection has challenges due to heavy thickness and variation in grain structure of the weld and parent material from different manufacturing process. Gamma ray radiography has limitation on detection of defects in double wall single image technique, which is the only suitable technique to meet the un-sharpness due to restricted access. This paper mainly focuses on the phased array ultrasonic testing for subsea manifold piping girth welds. Various ultrasonic studies such as wave propagation, attenuation and signal to noise ratio of different wave mode were performed for selection of technique. The suitable technique was selected after rigorous qualification using weld mock up blocks and results were validated.

Keywords: Phased Array, Shear Wave, 25% Cr Super Duplex, Weld inspection, Manifold.

Introduction

The welds in 25%Cr super duplex stainless steel piping have challenges in volumetric inspection due to heavy thickness and variation in grain structure of the weld and parent material from different manufacturing process. Most of the high thickness low diameter piping welds in 25%Cr super duplex stainless steel material is having difficulty in achieving un-sharpness in single wall single image (SWSI) radiography technique due to access the restrictions. The probability of detection is limited in double wall single image (DWDI) radiography technique due to double penetration thickness.

Ultrasonic inspection depends on the micro structure of material. Inspection is hampered because of severe attenuation of the ultrasound [1]. The scattering will be high with coarser grains as well as columnar grains in stainless steel. In order to improve ultrasonic examination of super duplex stainless steel piping weld, phased array technique was selected which provides greater flexibility for various inspection configurations in comparison with conventional manual ultrasonic techniques. Cautious selection of ultrasonic wave mode and frequency will help in reliable weld inspection.

This paper emphasis on selection of phased array ultrasonic technique for 25%Cr super duplex stainless steel welds through rigorous qualification process.

Phased Array Ultrasonic Testing (PAUT)

PAUT wave mode, frequency was selected based on the study of the ultrasonic propagation and attenuation property on the actual project material. Initially 25%Cr super duplex stainless steel material manufactured through Hot Isostatic Pressing (HIP) and extrusion was selected for the study. The piping ultrasonic weld inspection shall be in accordance with ASME B31.3 [3], ASME Section V [4], ISO 22825 [5] and ISO 17640 [6]. Side drill role (SDH) reference reflector was preferred over notch reflector to get better sensitivity. Notches will suffer from both echo-transmittance losses and mode conversion losses and a redirection of the beam away from the receiver [2]. The reference reflector for calibration and sensitivity was selected based on Ø1.5mm SDH. Surface notches shall be used as references for near-surface defects. 1.5 mm height and 20mm length surface notches were placed on the ID & OD surface. The weld will have coarse dendritic structure and more attenuation than parent material. To measure and compensate the different attenuation in parent and weld, the Ø1.5mm SDH reflectors were placed in parent material, weld fusion zone and center of the weld as shown in Fig.1.

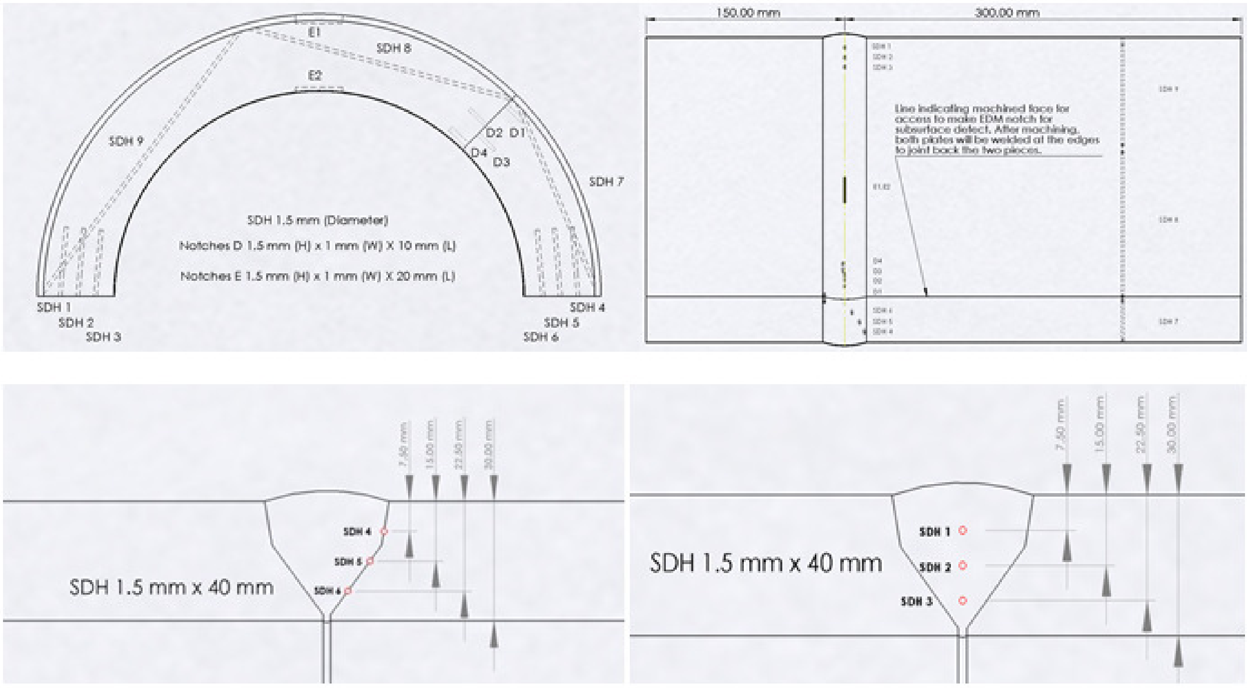

Fig. 1 Reference block sketch

Signal to noise ratio. Signal to noise ratio measurements on actual project materials with welds were made through varying test frequencies of angled compressional waves and shear waves. The phased array angled compressional wave of 5 MHz frequency generated on both HIP and extruded material is shown in Fig.2. The phased array shear wave of 5 MHz frequency generated on both HIP and extruded material is shown in Fig.3. Extruded pipe material had more noise compare to HIP material due to coarse grain structure in both angled compressional wave as well as shear wave in all frequencies tested. The signal to noise ratio was better in shear wave. The 5MHz shear wave was chosen for the procedure development as an optimum balance of signal to noise ratio and sensitivity to defect size compared with over the 7.5MHz and 2.25MHz frequencies on both HIP and extruded materials. Forged or other coarse grain material may require frequency lower than 5 MHz to compensate the attenuation.

HOT ISOSTATIC PRESSING MATERIAL EXTRUDED PIPE MATERIAL

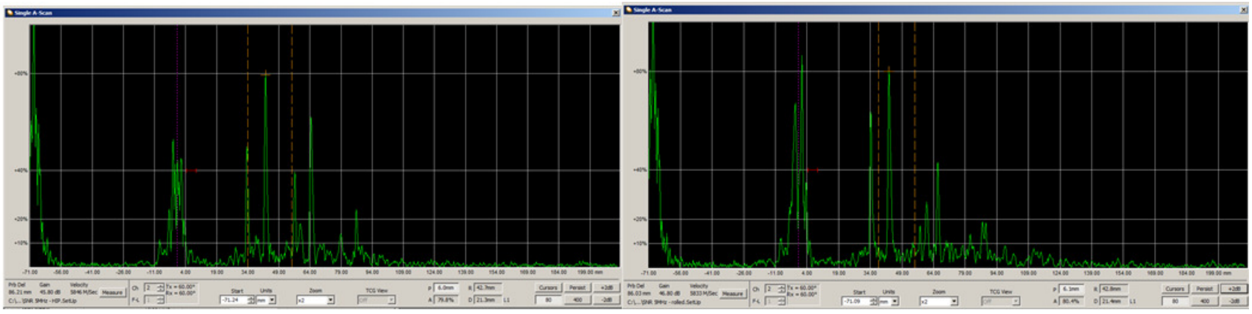

Fig. 2 Angled compresional wave signal

HOT ISOSTATIC PRESSING MATERIAL EXTRUDED PIPE MATERIAL

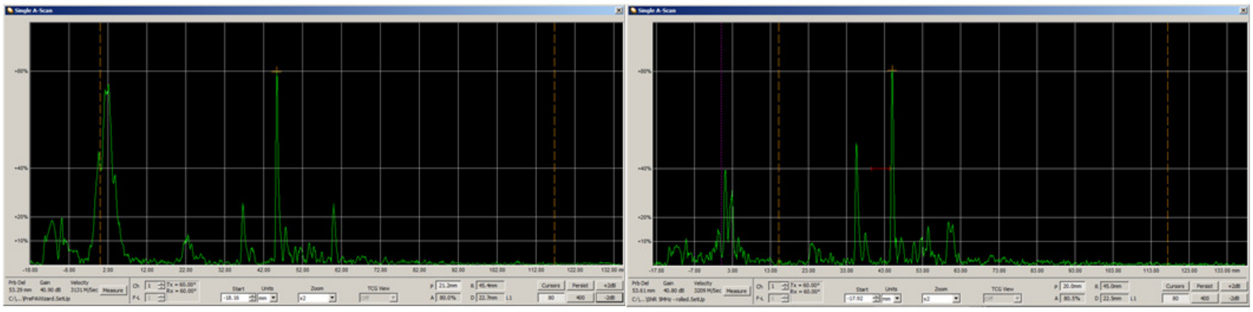

Fig.3 Shear wave signal

Velocity measurement. Velocity measurements for both materials were taken around the circumference of the pipe at 0^0, 90^0, 180^0, 270^0 and one random position. The velocity measurement for HIP and extruded material is shown in Table.1 & Table.2. The average measured velocity results show the 25%Cr super duplex stainless steel have velocity almost similar to the carbon steel. The slight variation may affect the beam angle of probe, so before start of the inspection beam angle deviation shall be corrected to the project material.

Velocity on HIP materials using 5MHz frequency						Average
Positions on pipe	0 deg.	90 deg.	180 deg.	270 deg.	Random	
Thickness [mm]	30.54	30.53	30.54	30.5	30.5	30.5
HIP Compression [m/s]	5841	5838	5842	5838	5839	5839.6
HIP Shear [m/s]	3128	3128	3134	3134	3130	3130.8

Table.1 Velocity measurement on HIP material

Velocity on Extruded materials using 5MHz frequency						Average
Positions on pipe	0 deg.	90 deg.	180 deg.	270 deg.	Random	
Thickness [mm]	31.84	30.55	29.3	31.7	30.85	30.85
Extruded Compression[m/s]	5845	5795	5795	5815	5813	5812.6
Extruded Shear [m/s]	3211	3213	3192	3186	3201	3200.6

Table.2 Velocity measurement on extruded material

Attenuation measurement. Attenuation measurements were taken in the parent material and weld separately using 5 MHz frequency 60^0 shear wave and special 0^0 shear wave probe. The gain and metal travel distance of ultrasound in half skip and full skip were used for calculation. The average attenuation in HIP parent material was 0.084dB/mm and extruded parent material was 0.098dB/mm. The average attenuation in weld material was 0.22dB/mm. The attenuation measure clearly shows the weld have more attenuation compare to the parent material form HIP and Extruded process.

Sensitivity measurement. Sensitivity measurements were taken using the Ø1.5mm SDH placed in the parent material, weld fusion zone and center of the weld. All the Measurements were taken on both sides of the weld for the SDH placed in weld center. To pass the weld ultrasound requires more dB due to the high attenuation in weldment due to the coarse grain structure.

	Parent Material (PM)			Fusion zone			Centre of weld (Both sides)			Fusion zone by passing sound across the weld		
Depth of SDHs	1/4T	1/2T	3/4T	1/4T	1/2T	3/4T	1/4T	1/2T	3/4T	1/4T	1/2T	3/4T
HIP Upstream (dB) Downstream (dB)	55.7	50.3	45.6	51.2	50.8	50.3	54.2 53.4	51.2 54.7	44.4 53.3	64.2	55.0	50.4
Extruded Upstream Downstream (dB)	58.1	55.5	45.9	60.6	56.7	53.5	68.2 66.2	60.8 61.9	57.6 52.0	68.3	54.8	51.9

Table.3 Sensitivity measurement

PAUT qualification

The reliability, repeatability, defect detection and sizing capabilities of the PAUT shear wave inspection was carried out using specially prepared qualification mockup weld blocks with artificial reflectors of known size. Surface and embedded artificial reflectors were placed in the welded block for qualification. ID & OD surface notch of 1mm deep was placed for surface detection. The embedded artificial reflector were made with different height, but the length and width of all embedded artificial reflectors kept same as 10mm and 1mm except the 3mm height as shown in Table.4. Placements of the reflector were spread across the weld at different depth as shown in the Fig.4. All the artificial reflectors were prepared using EDM slot notch.

Embedded artificial reflector dimension			
EDM slot notch	Height (H) [mm]	Width (W) [mm]	Length (L) [mm]
A	0.8	1	10
B	3	1	6
C	1	1	10
D	1.5	1	10

Table.4 Artificial reflector dimension

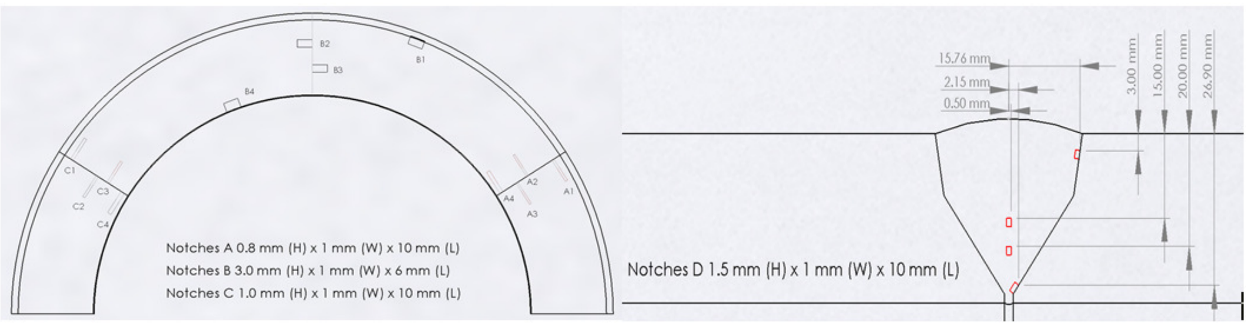

Fig.4 Qualification block

Scanning of qualification block. The qualification blocks with artificial reflectors were scanned with PAUT shear wave full skip technique. For the inspection 64 and 32 elements probe were used with 5 MHz frequency was selected as per the signal to noise ratio study. The scan plans were prepared using ES beam tool software version 5. Single line scan from either side of the weld were selected with different sectorial and linear groups in scan plan. Pseudo tandem technique was selected to cover the fusion zone on the 10^0 weld bevel at the top surface only in 64 elements probe.

Blind trails. Four 8" diameter and 30mm thickness welded 25%Cr super duplex stainless joints with V bevel configuration were taken for blind trails. The joints were radiographed with DWDI technique and no significant indication found. Then joint were scanned with PAUT.

Result and discussion

The scanning of qualification block performed on vertical and horizontal position of the piping spool. Scans were performed in clockwise and counter clockwise direction. Also scans were performed with different operators. The recorded scan data from all the position shows the same results confirmed the reliability of this inspection technique. 3 consecutive scan were performed with datum point at 12, 3, 6 & 9 o'clock positions. Each weld was scanned three times by removing the scanner and fixing it again before each scan. Also index offset position of the probe was changed to -1mm, -0.5mm, 0.5mm and 1mm form the original scan plan and scan data were recorded. The results obtained on all the scans were same and repeatability of the inspection is confirmed. The detected defect in the scan data were cross checked with the artificial reflectors placed on the qualification block. The scan results from 64 elements probe detected all the artificial reflectors placed in the block. Fig.5 shows the embedded reflectors detected from 64 elements probe.

The scan result form 32 elements probes detect all the reflectors except the reflector placed 3mm below the top surface. The defect detection in 64 elements probe with single line scan was good and 32 elements probe require additional line scan with different offset or additional testing. The sizing od the reflectors performed without removing any over trace from calibration scan and found all the reflectors were oversized due to beam spread.

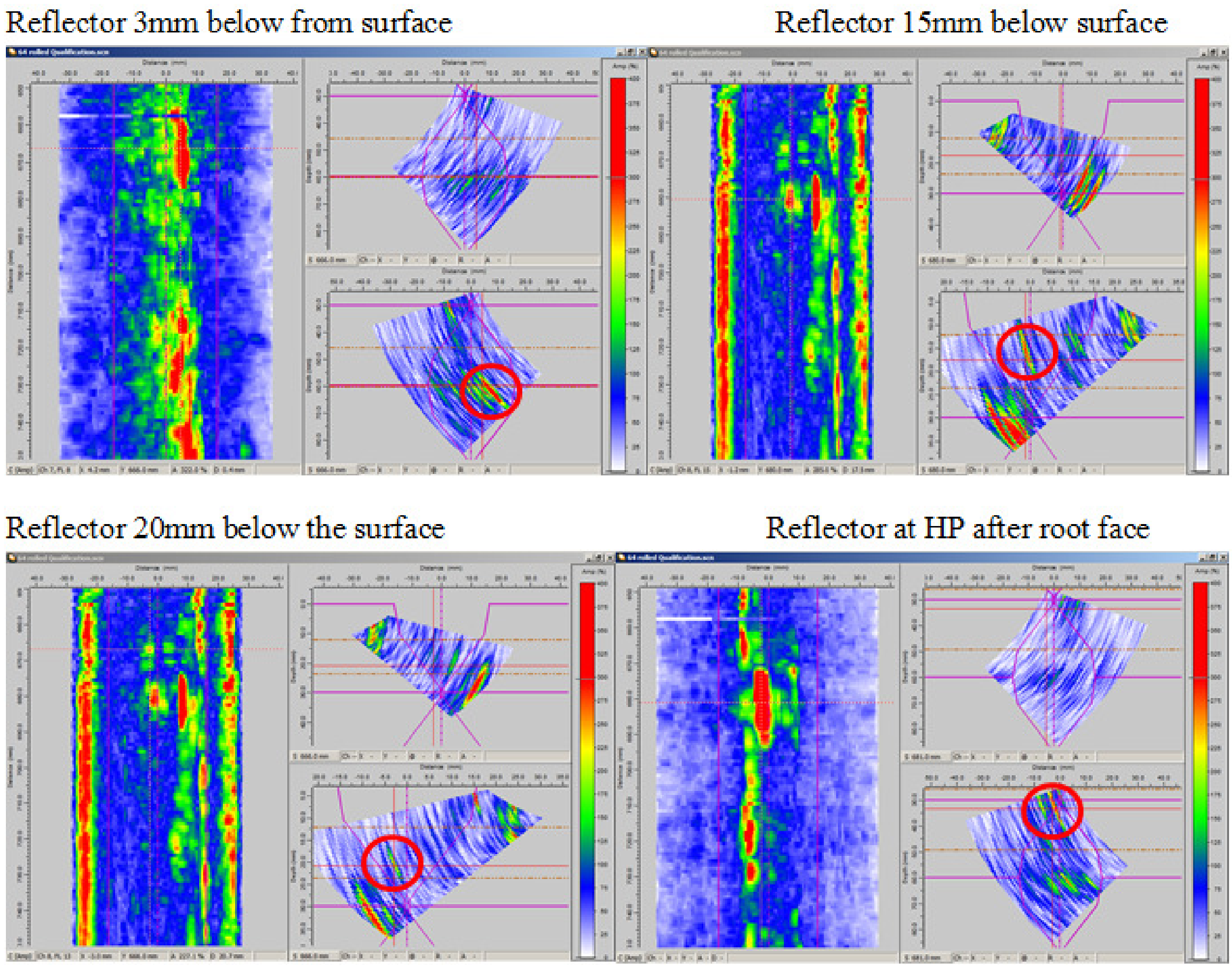

Fig.5 PAUT qualification scan image with embedded artificial reflector

The blind trail of PAUT scanning shows one joint with an intermittent lack of inter pass fusion discontinuity indication of 79mm long (length calculated with interaction rule) and at the maximum depth of 22mm from top surface as shown in Fig.6. In the same weld scan length area a cluster porosity of 12mm long at different depth around 14mm from top surface. The weld was selected for macro using salami cross section of the weld. The weld was cut into half and radiographed with SWSI technique on the location identified with discontinuity in PAUT. The SWSI radiographs picked up the cluster porosity of 14mm long and inter pass lack of fusion was missed. The Macro shows the presence of discontinuity in the welds as shown in Fig.7.

Conclusion

The ultrasound propagation study clears shows the 25%Cr Super duplex stainless from exhibits good results with shear wave compare to the fully austenitic material. The balanced ferritic and austenitic structure in 25%Cr super duplex stainless steel shows good signal to noise ratio but the attenuation is varying with different manufacturing process material due to the grain size. Also the weld has more attenuation. Attenuation compensation shall be placed in during inspection for each change weld process, bevel configuration and weld consumable for improved reliability on the inspection.

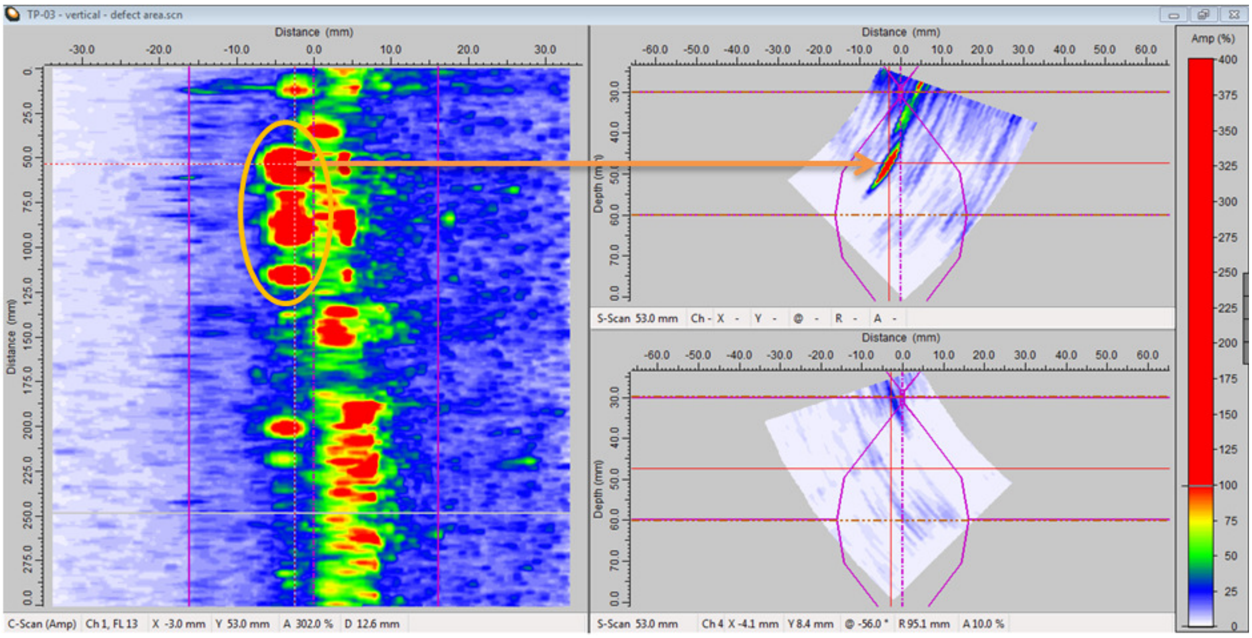

Fig.6 PAUT scan image with weld discontinuity

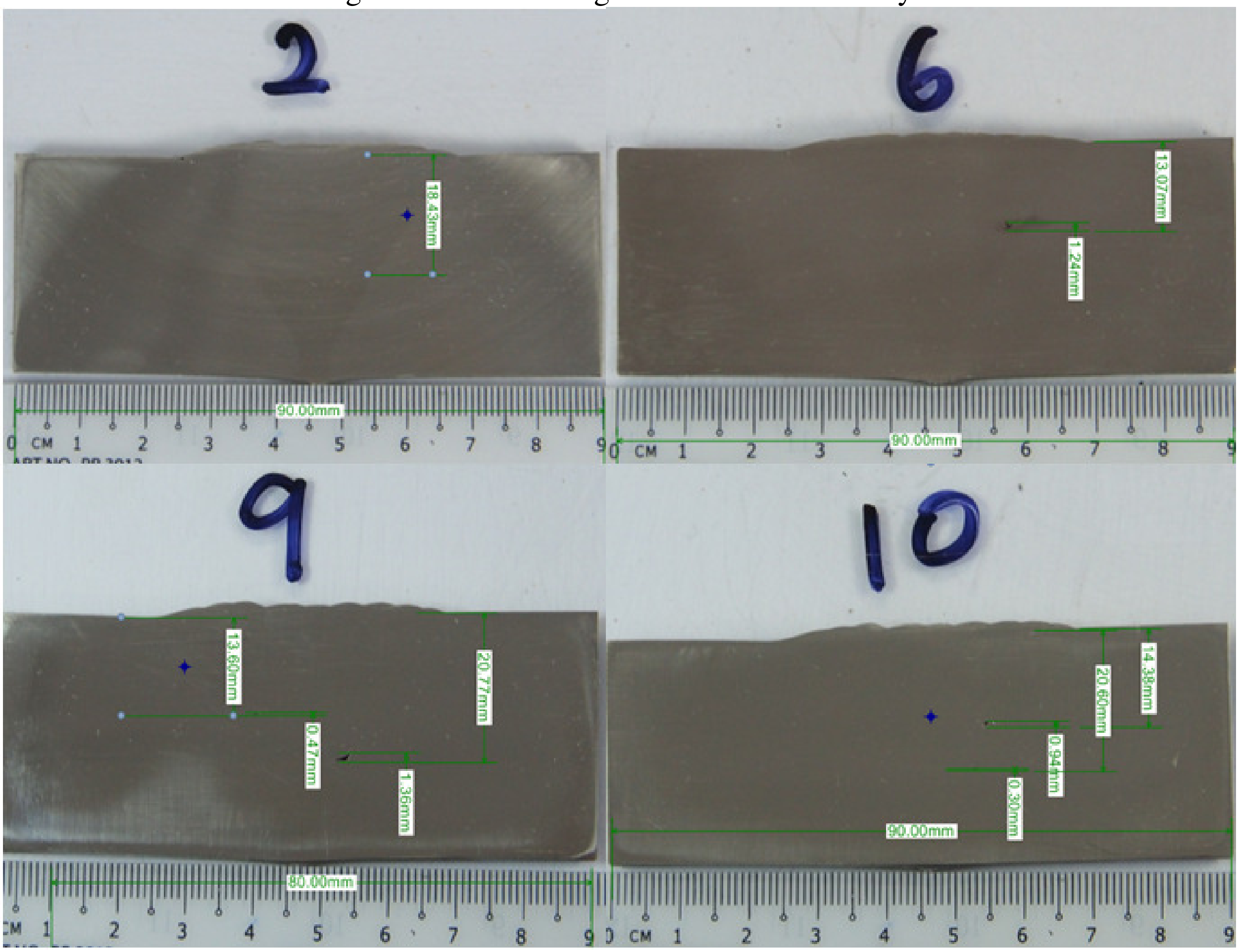

Fig.7 Macro images of weld discontinuity

The PAUT probes and inspection group shall be selected appropriately to get 100% coverage as well as detection. The scan plans may have 100% coverage but detection is depends on the orientation. The 32 element probe requires additional line scan or manual ultrasonic inspection with 70^0 beam angle. Adding additional creep wave and TOFD may help the detection capability in PAUT. The coarse grain structure in 25%Cr super duplex material from all manufacturing route show grain noise on TOFD scans. The TOFD can be complimented with PAUT for detection and not sizing the defects.

The defect evaluation on the defects detected in fusion zone shall be evaluated with sensitivity setting based on the reference reflectors placed in fusion bevel. The defects evaluation on the defects detected in weld center shall be evaluated with sensitivity setting based on the reference reflector on the fusion bevel by passing the ultrasound across the weld. The parent material from of forging other process with coarse grain structure may have more attenuation and shall be compensated accordingly.

The results of blind trail prove the probability of detection is very good in PAUT compare to radiography. Before start of inspection on 25%Cr super duplex stainless steel requires a study of ultrasonic propagation for selection of inspection technique and qualification is required to test the reliability and repeatability of the selected inspection technique.

Acknowledgement

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[2] Ed Ginzel, "Fun with CIVA"

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[4] ASME Section V, "Nondestructive Examination"

[5] BS EN ISO 22825:2012, "Non-destructive testing of welds — Ultrasonic testing — Testing of welds in austenitic steels and nickel-based alloys"

[6] BS EN ISO 17640:2010, "Non-destructive testing of welds — Ultrasonic testing — Techniques, testing levels, and assessment"