Ultrasonic Inspection of Austenitic Stainless Steel Weldments —Our Experiences

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Austenitic steel welded structures are widely used in power stations, petrochemical industries and nuclear industries. These welded structures pose unique problems for ultrasonic testing not experienced with ferritic steel welds. Since X radiography cannot be used in many cases (like inservice inspection, thick welds, planar defects, etc.), it becomes imperative that ultrasonic testing be used. To do this, the problems encountered during examination of austenitic steel weldments must be understood and solved.

The problems mainly arise due to the metallurgical structure in an austenitic steel weldment. Low thermal conductivity and absence of phase transformation in solidified structure lead, during a weld pass, to epitaxial growth of the grains formed during earlier weld passes. This leads to a very coarse and anisotropic dendritic grain structure (Fig. 1). The widely known manifestation of this coarse structure is the grassy peaks obtained on the oscilloscope screen. This takes place due to the scattering from the grain boundaries and makes the identification of defect signal rather difficult. Another well established fact is that both ultrasonic velocity and attenuation are strong functions of the crystallographic orientation in dendrites. Therefore, one is always uncertain about the signal strength coming back from the defect. In this paper, we have given some of our findings which have ameliorated the difficulties to some extent. Another manifestation of the strong dependence of ultrasonic velocity on crystallographic direction is the deviation of the apparent location of the same. This aspect would also be dealt with in this paper.

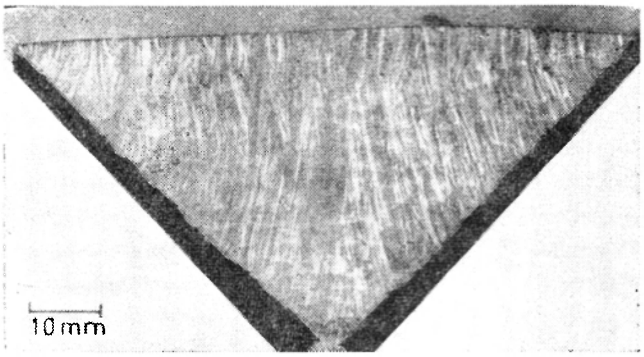

Fig. 1. Macrograph showing the cross section of 50 mm. thick austenitic S. S. weldment.

2. OPTIMUM CHOICE OF PROBES AND OTHER CONDITIONS

The choice of probes and test conditions are very important in ultrasonic inspection. Sensitivity, resolution and signal to noise ratio (SNR) are the parameters which one has to keep in mind during inspection of defects. Surface conditions, choice of couplant, weld geometry and the welding parameters also play an important role. Our experiences in achieving best compromises keeping the above facts in mind are the following :

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(a) Conventional transverse angle beam probes used for inspection of ferritic steel welds are less suitable for this purpose because of high scattering of these waves by coarse grain structure in the weldment. Transverse nature of the shear wave and coarse grain dendritic structure always results in higher attenuation. This gives rise to more noise and spurious signals which cannot be accounted for.

(b) Longitudinal angle beam probes are more suitable since scatter and hence attenuation, are less for these waves. Signal to noise ratio is greatly improved when these probes are used. These aspects become clearly evident when weld plates of thickness>10 mm are inspected. For small thickness plates<6 mm, both kinds of probes fare equally well. Fig. 2 compares the signal to noise ratio obtained from slag inclusion in 12 mm thick SS weld pad when longitudinal and transverse angle beam probes are used. It is clear that SNR is better for longitudinal wave probes.

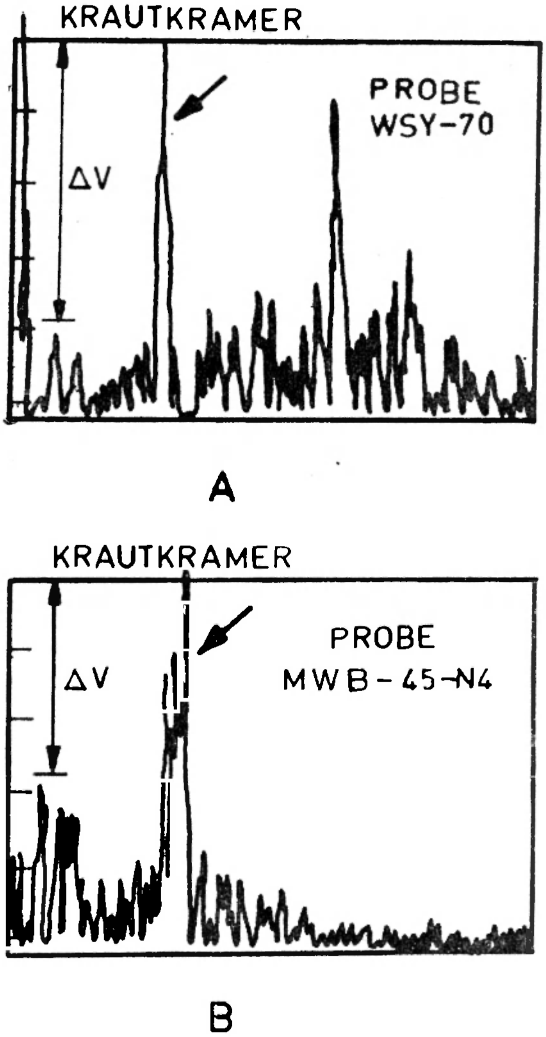


Fig. 2. Defect signal from slag inclusion in 12mm. thick austenitic 316 S.S. weld detected by (A) longitudinal angle beam 70° probe (B) transverse angle beam 45° probe.

(c) Higher frequencies always result in better resolution, but at the same time have higher attenuation. Our experience shows 4 MHz are best compromise for all practical purposes.

(d) Longitudinal angle beam probes of steeper angle (70°) are preferred while testing welds with crown retained, the reason being that unlike transverse angle beam probes, longitudinal angle beam probes have to be operated within the half skip distance in order to avoid mode conversion. Obviously, one is left with no choice other than using steeper angles. This is specially the case with weld plates <18 mm.

Since it is well established that longitudinal wave travelling at an angle 45° to the dendritic structure has low attenuation and maximum velocity in that direction[1,2], this angle beam probe is more efficient in defect detection and also gives rise to less error in the defect location[3]. But this would be of help only when weld crown is removed.

(e) Reference standards for each type of weldment are a must. As far as possible, it is desirable to maintain same set of welding parameters used for reference weld pad. Side drilled holes and through drilled holes in case of thicker welds (>10 mm) and side drilled holes in case of thinner welds serve as good reference.

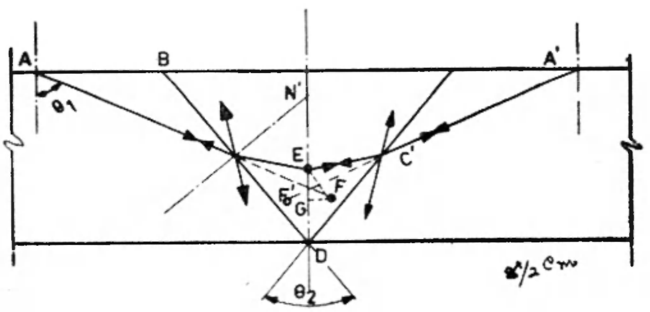
(f) It becomes necessary to grind the root weld to the surface in order to locate defects concentrated near the root weld.

3. ASSESMENT OF DEFECT LOCATION

Another major problem during ultrasonic testing comes from (i) deviation of sound beam at the parent metal/weldment interface, and (ii) beam skewing[4] due to the anisotropic nature of the grains. Due to these, the apparent defect locations determined from oscilloscope screen range get widely separated from the actual defect location. In the present day technology, not only the defect indication but also the exact defect location along with the shape and size are important. If these ar- known, then their role on the components under service stresses can be assessed. In this paper, we have attempted to find the mislocation of an actual defect caused by refraction of sound beam at the interface. We have developed computer programmes to ease the tedious calculations involved.

Fig. 3 shows a sketch of an idealised butt weld cross-section. Due to the differences in the sound velocities in parent material and the weldment, the sound beam from the probe (with centre A) gets partly refracted at C. However, the apparent defect location as would be determined from the oscilloscope range would be at F. It can be noticed from the figure that we have assumed CE to be a straight line for simplification, implying that beam skewing is not taking place. Fig. 3 also shows that if the probe is placed on the other side of the weld, i.e., at A', the same defect would be apparently located at F'. This means for one defect, two defects would be indicated.

The magnitude of deviations would be function of the following : (a) Probe angle θ_1, (b) weld angle θ_2 which would determine the angle at which the sound beam would strike the parent metal/weldment boundary, (c) distance by which the sound beam has to travel into the weldment in order to reach a defect and (d) velocity of sound beam in the weldment which would determine the angle of refraction and the time to reach the defect (ACF). The separations between the screen range and the geometrical range can be computed through the use of straight forward geometrical relationships.



A,A' = Probe Centres
θ = Probe Angle
E = Actual Defect
FF' = Location as determined from the Oscilloscope Screen Range
BCD = Butt Weld

Fig. 3. Idealised butt weld cross section with a hypothetical defect location inside.

For the purpose of calculations, we have assumed the presence of spherical defects of 2.5 mm dia. on the centre line of the weld at various distances from the top of the weld. Probe angles chosen were 45° and 70°. Weld angles were arbitrarily chosen at 65° and 80°. Computations have been carried out for plates of various thicknesses (12, 25, 50 mm) and for the case of single V and double V welded joints. We have considered longitudinal angle beam sound at 0-½ skip distance. From the reported values of velocities[5] as function of direction with respect to dendritic axis, we have taken the maximum and minimum velocities to be 6200 m/sec. and 5100 m/sec. respectively and have varied the velocity in weldment in steps of 100 m/sec. Parent metal velocity is assumed to be 6200 m/sec.

The results of these theoretical calculations for weld, 50mm thick, weld angle 80° and probe angle 70° are shown in Figs. 4-7.

The results of the actual experiment carried on 50mm thick radiographic quality weld are shown in Fig. 8 along with the theoretically predicted mislocation in the actual position of the defect. A1, A2, and A3 are the defect locations predicted by theory and experiment respectively from side A and vice-versa for B1, B2 and B3.

4. DISCUSSION OF THE RESULTS

Fig. 4 and 5 give deviation of defect location in vertical and horizontal direction respectively as a function of actual defect position in weldment. This has been shown for three longitudinal velocities in

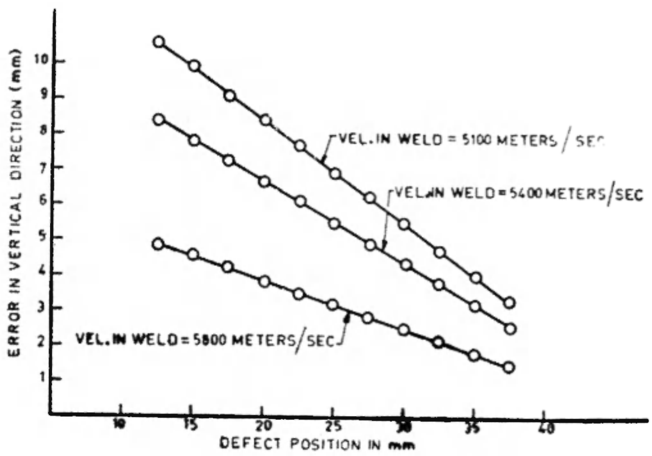


Fig. 4. Deviation of defect locations in the vertical direction as functions of defect position measured from top and at three sound velocities in weldment.

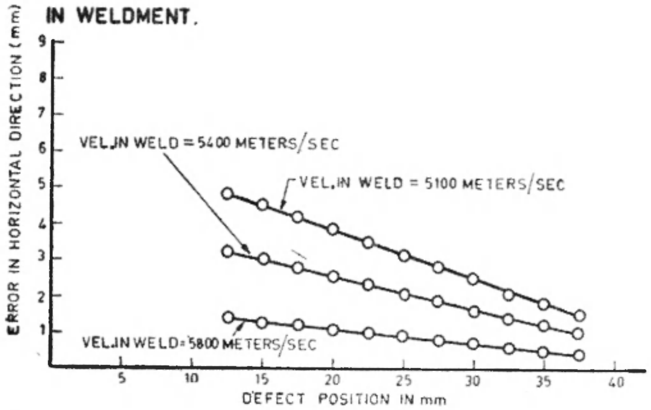


Fig. 5. Deviation of defect locations in the horizontal direction as functions of the defect positions measured from top of weld and at three sound velocities in the weldment.

weldment, namely 5800, 5400 and 5100 m/S. In the absence of any knowledge of velocity in the weldment, the area enclosed between the first and third line give an idea about the error range in the position of mis-location of the defect.

Fig. 6 and 7 are the graphs showing vertical and horizontal deviations in the position of a defect respectively as a function of longitudinal velocity in the weldment for different defect positions in weldment. For the known position of a defect, one can get an idea about the deviations from the graphs 4 and 5. Knowing the deviations, the approximate velocities in the weld along the direction of the probe angle can be got by graphs 6 and 7.

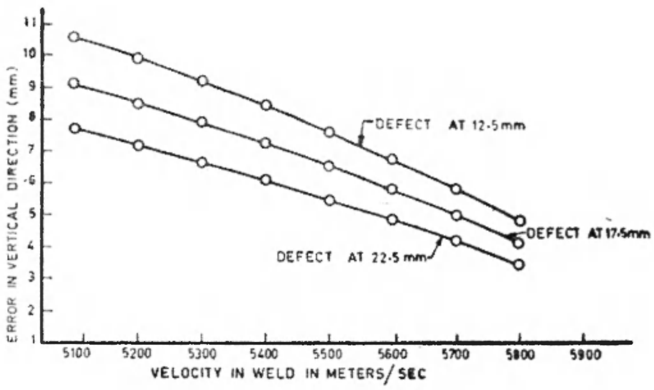


Fig. 6. Deviation of defect location in the vertical direction as functions of sound velocities in weld metals and for three values of defect positions measured from top.

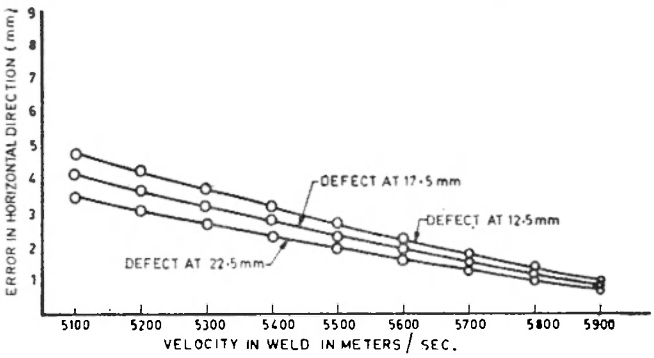


Fig. 7. Deviation of defect locations in the horizontal direction as functions of sound velocities in weld metal and for three values of defect positions measured from top.

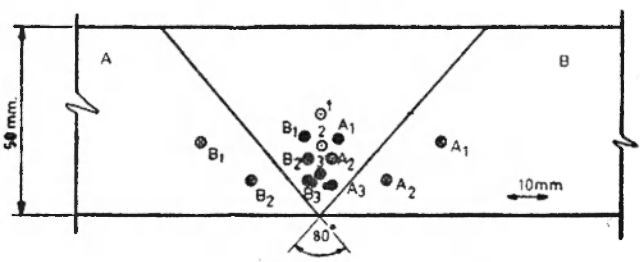
The other observations made from these graphs are :

1. The deviations in the vertical direction are greater than the deviations in the horizontal direction.

2. As the defect locations are situated more and more away from the top of the weld, the deviations become increasingly smaller. In other words, the more the sound beam has to travel through the weldment, the more would be the deviation.

3. Experimental results deviate significantly from the theoretical prediction for the holes nearer to the weld top surface (Fig. 8). For example, the theoretical deviations in the vertical and

Plate Material S. S. 316
Arc welded with Philips
R. S. 316 B Electrode



. Actual side drilled holes of dia. 2.5 mm.
● Theoretical prediction of the holes, positions
× Experimental detection of the holes, positions

Fig. 8. Cross section of 50 mm. thick austenitic S. S. weld.

horizontal directions for the defect hole at 38.5 mm from the top of the weld surface are 3.0 mm and 1.4 mm. Experimental deviations are 3.5 and 3.0 mm, whereas for the hole at 31.5 mm from the weld top surface, the theoretical deviations in vertical and horizontal directions are 5.6 and 2.6 mm and the experimental deviations are 10 mm and 19 mm respectively. The possible reason could be the deviations introduced would be much more from the beam skewing effect. We are trying to develop a method to assess the skewing effects.

From the above observation, one can make some important remarks as regards the welding practices to be carried out till the theoretical approach becomes mature enough to be applicable in practical circumstances. As it is very clear that the deviations will be severe when sound travels more distance in the weldment, it would be beneficial if in ultrasonic testing, the ultrasound has to travel as small a distance as possible through the weldment regions. The possible means to attain these are :

(a) resort to weld designs which would enable placing the probes at both sides (top and bottom) of the weldments ;

(b) resort to double side welding (like double V welding), wherever practicable; and

(c) resort to narrow gap welding which would also cut down the fabrication cost. This also would reduce the attenuation of the sound beam and ease the operation of inspection.

5. CONCLUSIONS

We have optimised the conditions for the choice of probe for ultrasonic inspection of sustenitic welds.

Longitudinal angle beam probes are better suited for the purpose. 4 MHz frequency is a better compromise between resolution and sensitivity. Reference standards are necessary for each variety of weld. From the inspection point of view, the design at the weld geometry has to be taken into consideration to suit the ultrasonic testing wherever it is possible.

Knowledge of velocity in the direction of probing in the weldment is necessary to assess the deviation in defect location due to beam refraction at the parent/ weldment boundary. Exact theories to explain the large deviations in the defect location need to be explored. Further accumulation of data from actual application will be necessary to definitely establish the validity of theories proposed.

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