KAPL-P-4045
CONF-760506--2

Ultrasonic Inspection of Austenitic Cladded Steel

by

P. Anderson
D. A. Gavin

Introduction

Ultrasonic inspection of cladded steel has received significant attention during the past few years with the advent of Section XI to the ASME Boiler and Pressure Vessel Code. Since cladding is normally applied as a cast austenitic material to a forged alloy steel there is often structural differences between the two; particularly with regard to grain size. These differences are most pronounced at the bimetalic interface where the weld bead produces an uneven curvature to the fused boundary. It is very difficult to quantify the effect that these structural differences will cause in the ultrasonic inspections. However, previous work at such laboratories as the Southwest Research Institute, reference (a), have shown that such effects can introduce serious errors in defect analysis.

While it is recognized that structural differences will remain an inherent property of cladded metals, it should be possible to determine what techniques or parameters can be chosen for an ultrasonic inspection that will minimize the adverse effects of cladding. A study was conducted at KAPL to this end.

The results of this study and the recommended inspection techniques are presented in this paper.

Reference (a) "In-Service Inspection Program for Nuclear Reactor Vessels" Southwest Research Institute, Jan. 7, 1972

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Abstract

A summary of important properties or characteristics associated with the ultrasonic inspection of austenitic cladded materials is presented. These characteristics include attenuation differences, angle beam mis-direction, and zero degree angle beam reflections. The latter characteristic appears as a false 3/8 node shear wave signal, when testing at an angle of 45 degrees. This signal is shown to originate in the unusual grain structure of austenitic cladding. The relative amplitude of the false shear wave indication is shown to vary inversely with the size of the search unit (area) and directly with the test frequency. It is further noted that this effect is sensitive to the direction of clad welding; being significantly greater if the ultrasonic beam is directed perpendicularly to the welding direction. Figures depicting the above conditions are presented together with suggestions for dealing with these adverse testing properties.

Zero Degree Shear Wave

Perhaps the most unusual characteristic found during inspections through austenitic clad is the presence of a shear wave signal that appears to come from a back reflection. This signal is produced by a 45° shear wave and appears approximately at a 3/8 node position. It is postulated that the signal is caused by scattering of the 45° shear wave on the concave surface of the weld bead. It is believed that a large number of impurities are collected at the outer surface of the bead which causes an impedance mismatch with the relatively pure, internal crystal grains to produce this effect. Elastic anisotropies along the dendritic grain structure may also contribute to this scattering.

Accordingly when an incident 45° shear wave beam strikes a concave impedance interface, a portion of the beam is reflected to the bottom surface of the base metal. At the back surface the beam is completely reflected back along its initial path at a "zero degree" incident angle. Thus our designation of a "zero degree shear wave" for this effect.

This "zero degree" signal has been determined to be a shear wave from the following information.

1) The observed signal always appears at a 3/8 node position regardless of the forging thickness.

2) The observed signal can be moved in space by placing a reflector (void) directly below the transducer but outside the sonic path of the incident 45° shear wave.

3) Attempts to dampen the observed signal on the reflecting surface were not successful as would be expected only in zero degree incident shear wave reflection without mode conversion.

4) The time required for the observed signal to appear at a 3/8 node position is very close to the time required for a shear wave to undergo a simple reflection through the forging thickness.

5) Conversely if the aforementioned signal were a longitudinal wave then two back reflections would be observed in the same time period. They are not observed.

The amplitude of the zero degree shear wave is not insignificant as indicated by its measured values in Table I. As listed, the signal lies within typical reporting levels and in some cases above the rejection level when measured relative to a standard calibration notch. Once the effect is identified, some

Table I

"Zero Degree" Shear Wave Amplitudes

Tranducer Dimensions	Test Frequency(MHZ)	Calibration* Signal (% FS)	Maximum Zero Degree Shear Wave (% FS)
0.5 in. diameter	2.25	80	100
0.5 in. x 1.0 in.	2.25	80	70
1.0 in. x 1.0 in.	2.25	80	40
0.5 in. x 1.0 in.	1.00	80	0
0.5 in. diameter	5.00	30	60

*Calibration reflector - square notch 3% of total thickness. Cross sectional area; 0.090 in. x 2.03 in.

steps should be taken to minimize its effect. The work performed at KAPL demonstrates that the "zero degree" shear wave signal can be minimized, if not eliminated, by selecting a large diameter transducer with a low test frequency for the ultrasonic inspection. Conversely high frequencies and small diameter search units will enhance the observed shear wave signal. These effects are demonstrated in figures 1 and 2 which show an inverse variation of signal amplitude with crystal size and frequency. It is further noted that the signal (zero degree shear wave) is strengthened when scans are made normal to the welding direction as opposed to parallel scans.

While it has been possible to identify a false signal originating in cladded forgings, one cannot neglect the real possibility of a genuine flaw falling at exactly the same 3/8 node position. This too can be identified because the false signal has an unusually short travel distance; usually less than twice the pulse width signal. A real flaw generally has a much greater travel distance; often an inch or more.

Attenuation Differences

Ultrasonic beam attenuation can be expected to be one or two orders of magnitude greater in an austenitic clad material than in an alloy steel. Attenuation measurements taken in the near field on cladded samples, with the alloy steel removed, gave the coefficients listed below.

Table II

Attenuation Measurements

Clad Thickness (in.)	Attenuation Coefficient (db/in)
0.320	20 ± 2
0.531	23 ± 2
0.813	26 ± 2

Measurements taken in the far field, on carbon steel alone, yielded a backwall decay pattern of approximately six decibels per reflection. Such a decay pattern is indicative of a zero value coefficient. These measurements were obtained with a 0.5 inch diameter, 2.25 MHZ transducer.

The measurements taken in the near field appear to be internally consistent with the higher values appearing in the transition region between the near and far fields where beam divergence adds to the measured attenuation.

FIG. 1

"ZERO" DEGREE SHEARWAVE

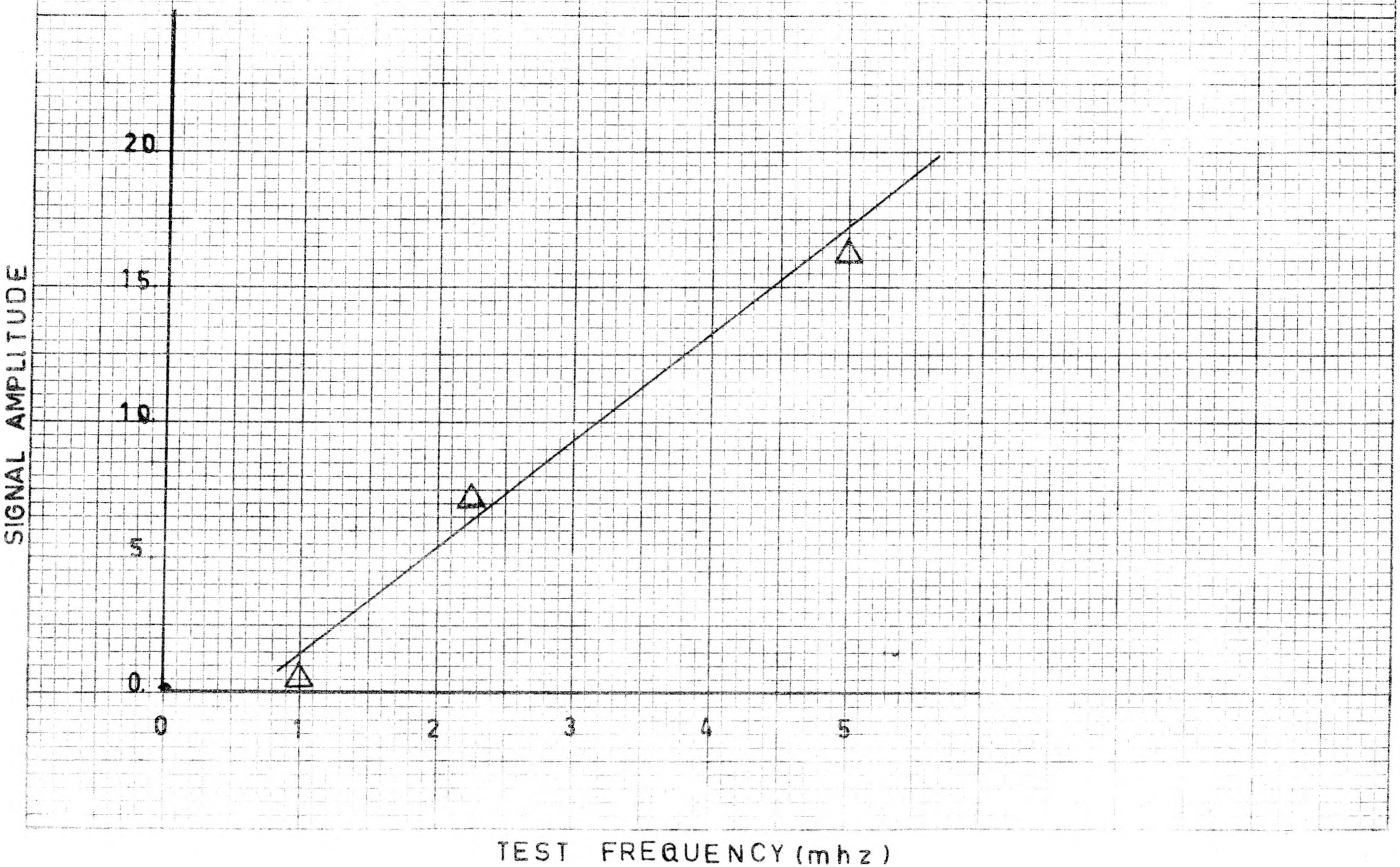
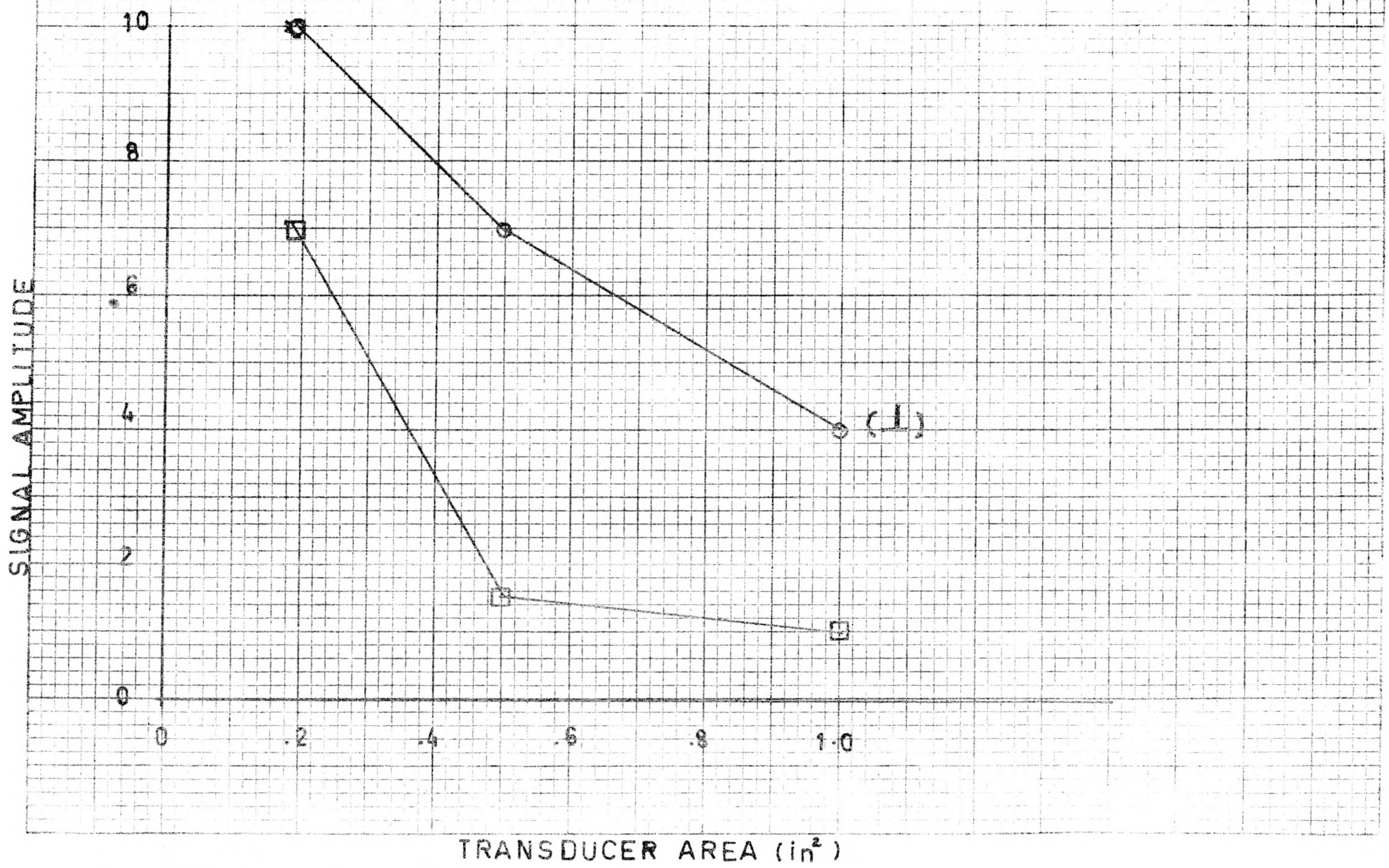


FIG 2

"ZERO" DEGREE SHEAR WAVE



Assuming a difference of 20 decibel/inch between the clad and base metal, the extra clad attenuation for longitudinal waves should amount to about 30 percent of the incident signal in typical applications. This value was confirmed by longitudinal wave tests on an alloy steel bar prior to and following the addition of about 150 mils of austenitic cladding.

Shear wave attenuation is more difficult to measure in the absence of a backwall reflection. However a number of relative measurements were made with a square notch as a reflector on cladded and uncladded steel blocks. These measurements gave the following results for an incident 45 degree shear wave beam.

Table III

Shear Wave Attenuation

Transducer Dimensions	Test Frequency (MHZ)	Relative Response Clad/Unclad (db)
0.5 inch diameter	2.25	10 → 20
0.5 inches x 1.0 inches	2.25	8 ± 2
0.5 inches x 1.0 inches	1.00	2 ± 1

By inspection, the high frequency, small diameter transducer gave the largest attenuation value. Therefore the attenuation can be minimized by choosing a large diameter, low frequency search unit.

Misdirection of Shear Wave Sound Beam

It is not unexpected for shear wave beams to be refracted at the clad-base metal interface. The degree of refraction can be exceptionally large and is due primarily to the combination of coarse grain and the uneven interface boundary rather than the impedance difference between the two metals. Our work indicates that the "misdirection" or extra refraction depends strongly on the sound wavelength and to a smaller degree, the beam size.

The measurements listed below were taken from corner reflections on the calibration blocks used to measure the relative shear wave beam attenuation.

Table IV

Shearwave Misdirection Angles

Transducer Dimensions (in.)	Test Frequency (MHZ)	Maximum Reflection Angle (Degrees)	Test Metal
0.5 x 1.0	2.25	45	Alloy steel
0.5 x 1.0	2.25	36	Cladded Steel
0.5 x 1.0	1.00	45	Cladded Steel
0.5 (diameter)	2.25	38	Cladded Steel

While the result at a test frequency of 1.0 MHZ may be somewhat fortuitous, it is indicative of the choice of transducers that should be used to identify flaw locations when testing through cladding; i.e. low frequency and large surface area.

Summary of Results and Conclusions

In order to minimize the adverse effects of cladding in performing an ultrasonic inspection, low frequency (1 MHZ) and large area (1" x 1/2") transducers should be selected. It has been demonstrated, that on a relative basis, the aforementioned parameters significantly reduce "zero degree" shear waves, beam attenuation and beam misdirection.

It is recognized that this choice will reduce both sensitivity and resolution in most applications. However, it has been demonstrated that the usual parameters, selected for defect analysis, are those that will introduce the most serious errors when inspecting through cladding.