CHARACTERIZATION AND INTERPRETATION OF ULTRASONIC STRUCTURAL ECHOES IN BIMETALLIC WELDS

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INTRODUCTION

Ultrasonic testings of bimetallic welds often show the presence of false calls. In pulse-echo mode at oblique incidence, these false calls are detected close to the backwall. They are generally distributed along lines parallel to the buterrings. The phenomenon is disturbing because it limits the efficiency of ultrasonic testing in the area of the backwall : false calls can be misinterpreted for echoes from defects or they can mask the presence of real defects. If a defect is detected, they also limit the possibility of characterization.

The metallurgical structure and the anisotropic properties of bimetallic welds do not allow an easy interpretation of the phenomenon. Bimetallic welds contain large austenitic columnar grains with a dendritic structure. The different grain orientations can lead to beam deflection or mode conversion which can generate echoes.

The present paper aims at explaining these false calls mechanism of formation. An experimental study has been conducted to characterize the phenomenon. From the resulting data the phenomenon has been interpreted.

DESCRIPTION OF THE PHENOMENON

The phenomenon was studied on a mock-up containing a bimetallic weld ; it is composed for one side in low alloyed ferritic steel and for the other side in low carbon austenitic stainless steel. Both the butterrings and the weld are made of Inconel. The thickness in the axis of the weld is 106 millimeters.

Ultrasonic testings were carried out in pulse-echo mode in order to detect false calls. Tests were implemented with an immersed focused transducer generating 45° longitudinal waves with a 1 MHz center frequency. The focal depth of the transducer is 100 mm.

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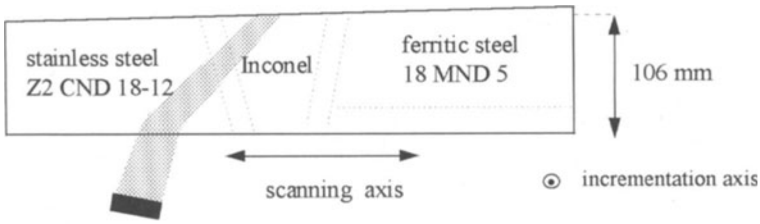

Figure 1 Experimental configuration.

The mock-up was tested in two opposite directions : from stainless steel to ferritic steel and from ferritic steel to stainless steel. The experimental configuration is described on Fig. 1.

False calls have been detected from both sides of the weld. Cscan images of echoes are shown on Fig. 2. The time of flight and the theoretical refracted angle indicate that false calls are localized in the weld close to the backwall. They are distributed along lines parallel to the butterings. The distance from butterings is different in the two directions of examination. False call amplitude along the line can reach 8 dB under the reference (measured from a 2 mm side drilled hole at the focal depth of the transducer).

EXPERIMENTAL CHARACTERIZATION

Ultrasonic Beam Propagation in the Weld

Through-transmission tests were carried out to study the beam propagation into the weld, especially at the position of false calls.

A wideband receiver in contact with the surface was scanned on the backwall for fixed positions of the transmitter. The recorded cartographies allowed the measurement of emerging points at the backwall. The comparison of wavepaths in the base metal and in the weld indicate that the beam is not much deflected inside the weld. The time of flight between the transmitter and the receiver confirmed that the actual wavepath is a 45° longitudinal one.

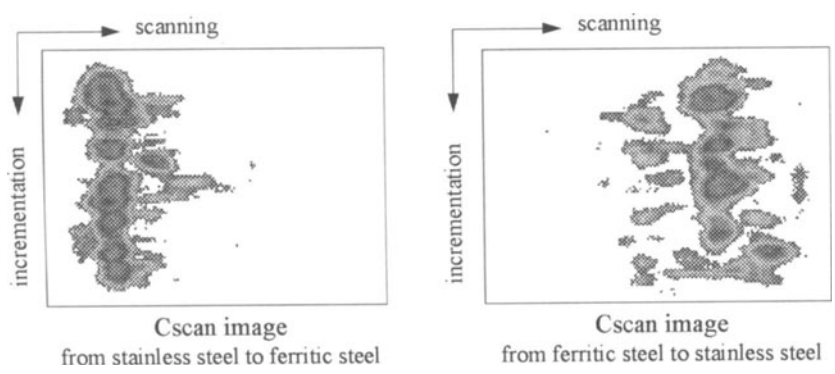

Figure 2 Cscan images of false calls.

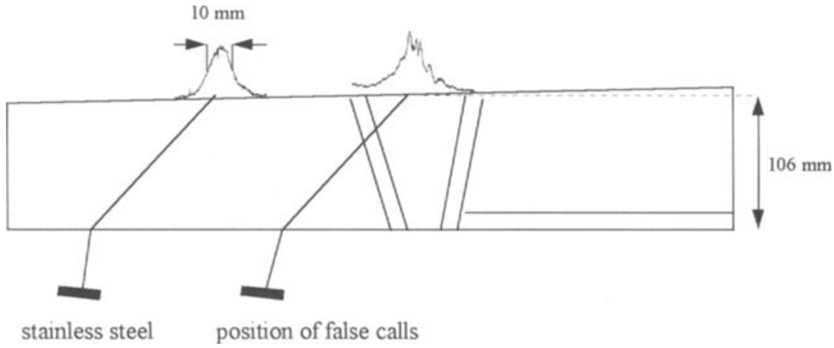

Figure 3 Longitudinal wavepath in the weld.

Emerging points measured in the base metal and in the weld (at false call positions) are shown on Fig. 3. The measured 45° longitudinal wavepath in the weld allow one to conclude that false calls do not result from a reflection of longitudinal waves at the backwall induced by a deflection inside the weld or at the interfaces.

The 45° longitudinal wavepath confirms the depth positioning of false calls near the backwall. In order to know if beam profiles could give us informations about the phenomenon, we observed these profiles at different positions. We noted that the ultrasonic field was characterized by an irregular distribution of energy, but the same deformations were observed whether the transmitter position was in a false call position or not (Fig. 4). No relationship was found between the longitudinal beam shape and the presence of false calls.

Influence of the Last Millimeters Near the Backwall

The time of flight and the wavepath indicate that the origin of the phenomenon is localized in the last millimeters near the backwall. So as to know the influence of these last millimeters, the backwall was machined in the middle area of the mock-up. Three thicknesses of steel were removed step by step. Between each removal, pulse-echo tests were carried out so as to follow the evolution of false calls.

One millimeter was first removed. This action induced an attenuation of false calls from 1 to 5 dB. Then, two additional millimeters were removed. This removal, equivalent to a welding pass thickness, led to an important attenuation of the phenomenon. In the same time, false calls appeared at 15 mm from the initial position. After the last machining, a thickness equivalent to two welding passes was removed.

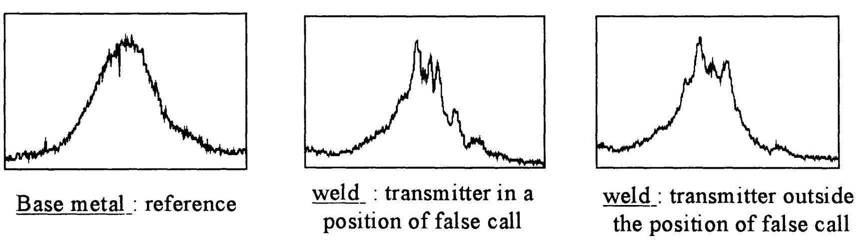

Figure 4 Beam profile in the weld (amplitude versus scanning curves).

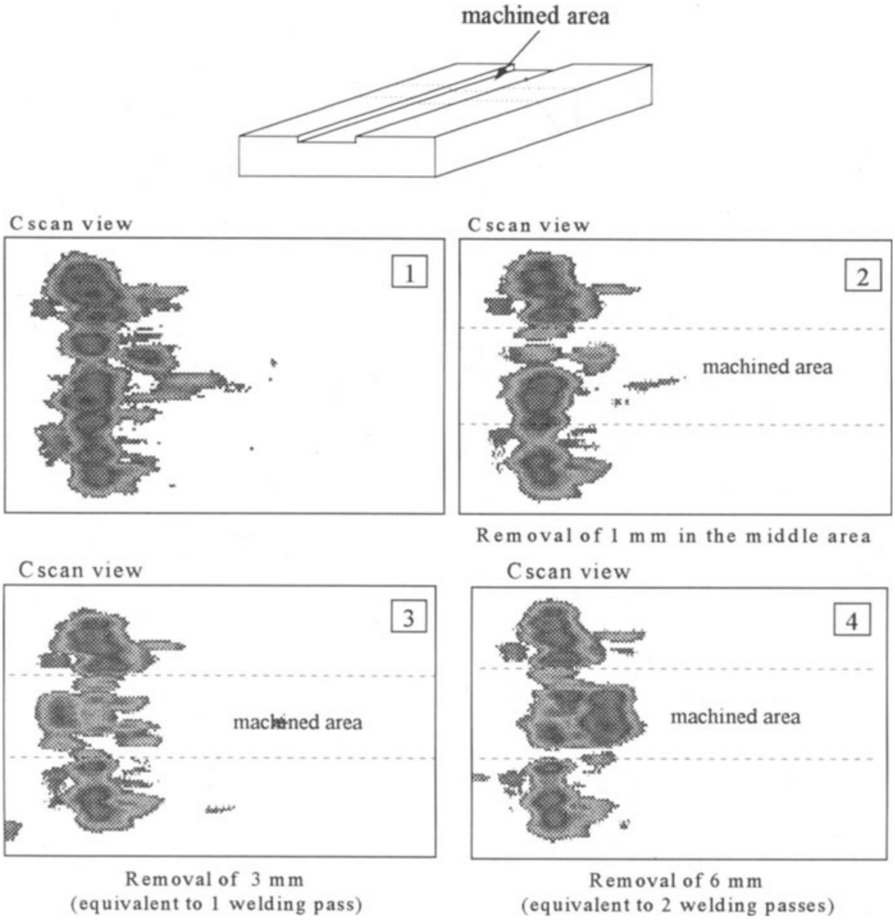

Figure 5 Evolution of false calls induced by a progressive reduction of the thickness.

The last machining led to the attenuation of false calls generated at the previous step and to the generation of false calls both at the initial position and at 15 mm on the other side. Results are illustrated on Cscan images on Fig. 5.

The evolution of the phenomenon after the removal of one or two welding passes (attenuation and generation in other positions) shows that the last welding passes determines the position of false calls. It confirms that the mechanism of echo formation is localized in the last welding passes.

All experimental results led to the following conclusions :

- the beam is not deflected in the position of false calls : it is propagating at 45° up to the backwall
- the time of flight and the wavepath indicate that false calls are localized close to the backwall
- the longitudinal beam shape has no distinctive feature at the backwall in the position of false calls
- the mechanism of echo formation occurs in the welding passes near the backwall.

THEORETICAL INTERPRETATION

Results of the experimental characterization allow an interpretation based on the anisotropic and the heterogeneous properties of the weld. This interpretation assumes that mode conversions can occur between adjoining passes due to the misorientation of the dendritic structure.

The wavepath can be described as follows : the longitudinal waves propagate at 45° up to the last welding pass boundary. At the boundary, the incident waves are converted into transverse waves with a phase velocity normal to the backwall. These waves are reflected on the backwall and they back-propagate to the transducer along the same wavepath as the forward propagation.

False call generation requires the following conditions : an appropriate dendrite misorientation between welding passes to convert 45° longitudinal waves into 0° transverse waves and the closeness of the backwall so as to limit diffusion of transverse waves before the reflection. The need of these conditions explains the distribution of false calls in the weld.

The propagation in anisotropic media can be predicted by considering the longitudinal and transverse wave slowness curves. To describe the specific mode conversion L45°/T0°, we considered the curves calculated for an orthotropic system. These curves were oriented in the same direction as the main dendrite axis in each welding pass, as shown on Fig. 6. The converted shear waves were deduced from the incident waves by projecting the quasi-longitudinal wave on the shear wave slowness curve normally to the boundary. The dendrite misorientation described on Fig. 6 enables the mode conversion of 45° longitudinal waves into 0° transverse waves (phase and energy velocity normal to the backwall).

EXPERIMENTAL VALIDATION OF INTERPRETATION

Further experiments were implemented to validate the theoretical interpretation : these tests intended to prove the presence of transverse waves near the backwall.

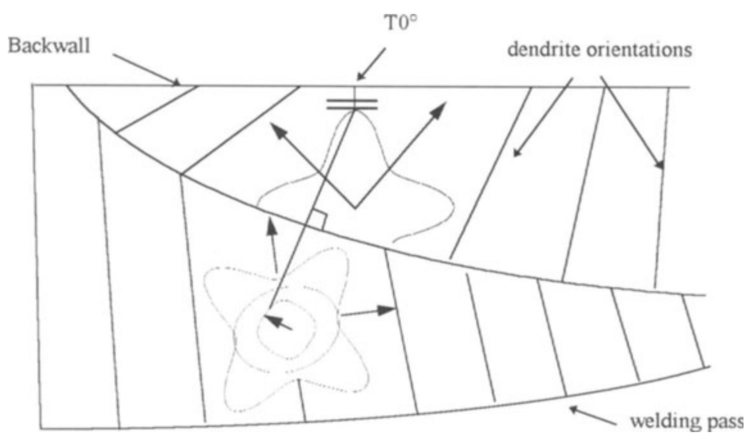

Figure 6 Description of the mode conversion between the last welding passes.

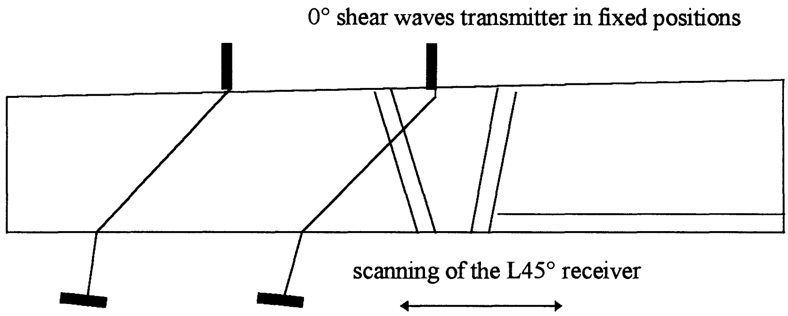

Figure 7 . Through-transmission tests with a T0° transducer.

Through-transmission tests were carried out with a 0° shear waves transmitter and a 45° longitudinal waves receiver. The receiver was scanned for fixed positions of the transmitter as shown on Fig. 7. In the base metal, energy was recorded by the receiver. It corresponds to the energy diffracted by the crystal edge of the transducer. In the weld, a greater energy was recorded. This result indicate that 45° longitudinal waves are generated in the weld from 0° shear waves. The time of flight shows that the mode conversion T0°/L45° occurs near the backwall.

Another experiment consisted in changing the coupling conditions at the backwall so as to observe the influence of different couplants on the phenomenon. Pulse-echo tests were carried out with three external media :

- air, which prevents the longitudinal and transverse waves radiation through the backwall
- water which allows the radiation of longitudinal waves through the backwall
- steel, with a specific coupling layer allowing the radiation of transverse waves through the backwall.

The water contact had no influence on the phenomenon. With a specific couplant allowing transverse waves radiation through the backwall, the phenomenon was attenuated from 3 dB as shown on Fig 8. This attenuation indicates that transverse wave propagation is involved in the phenomenon.

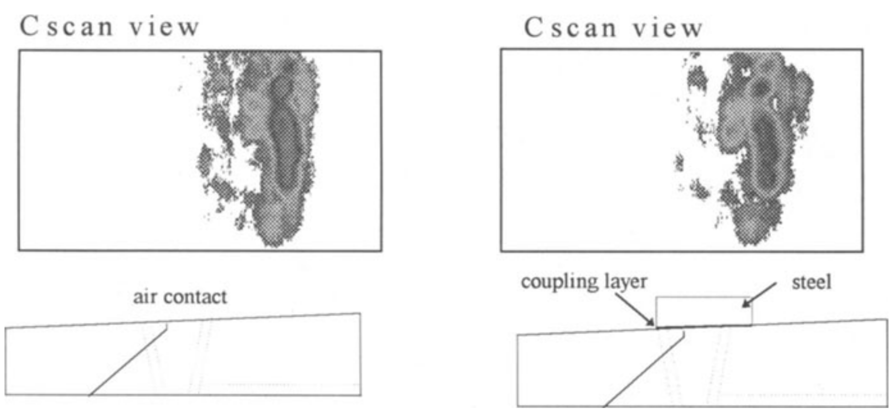

Figure 8 . Influence of coupling conditions at the backwall.

CONCLUSION

The examination of a bimetallic weld in pulse-echo mode with 45° longitudinal waves showed the presence of false calls close to the backwall. A study was undertaken to identify the origin and the mechanism of echo formation.

Experimental results showed that longitudinal waves are not deflected in the weld, at the position of false calls. The origin of echo formation was localized in the welding passes near the backwall. These results led to an interpretation based on the anisotropic and the heterogeneous properties of the weld : false calls result from a reflection at the backwall of mode converted waves generated at the last pass boundary. An appropriate misorientation of the dendrite structure in welding passes leads to the conversion of 45° longitudinal waves into 0° transverse waves. When this specific mode conversion occurs near the backwall, the converted shear waves are reflected and back-propagate to the transducer along the same wavepath.

This interpretation was validated by the increased energy received by a 45° longitudinal waves transducer when 0° shear waves are transmitted in the weld from the backwall. The attenuation of false call amplitude with a coupling layer allowing radiation of transverse waves through the backwall also confirms the interpretation.

Further experiments will be conducted to identify the direction of propagation of mode converted transverse waves into the last welding passes. Modeling studies will also be made to predict the beam propagation as a function of dendrite misorientation and tilt of the welding pass boundary.