APPLICATIONS OF NON CONTACT ULTRASONIC EVALUATION

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INTRODUCTION

The non contact generation and detection of ultrasound has recently received considerable attention and the first industrial applications are now emerging. Attention has focused on optical methods and in particular the techniques of laser ultrasound. However there are many applications where the cost of the laser solutions to both generation and detection are prohibitive and other cases where the limitations of interferometric detection are decisive.

In this paper we will consider three NDE problems that require a non-contact solution but where the full laser ultrasound solution is impossible. Firstly we will consider the use of an electromagnetic acoustic transducer (EMAT) send/receive system for measuring the wall thickness of hot mild steel galvanising tanks. Secondly the use of a laser generation, EMAT detection arrangement to monitor the melting process of a range of industrially important metals. Finally we will describe a miniature hand held laser/EMAT system that has been optimised for use in the oil industry.

EXPERIMENTAL DETAILS

The EMAT's used in the present investigation were sensitive to SH shear waves and have been described in detail elsewhere[1]. Water cooling allowed them to be used with minimum stand off from the hot surfaces. The pulsed laser used in two of the cases for generation of ultrasound was a Q switched Nd:YAG with a rise time of less than ten nanoseconds.

THE MILD STEEL GALVANISING TANK

The galvanising of steel components is a routine operation around the world to provide a measure of protection against corrosion. The galvanising is achieved by dipping the component into a bath of molten zinc. The zinc is held at a temperature of approximately 460°C in a mild steel tank which uses either electrical or gas-fired heating. The molten zinc forms an alloy with the steel, known as dross, at the interface between the two metals. There is therefore a steady decrease in the thickness of the

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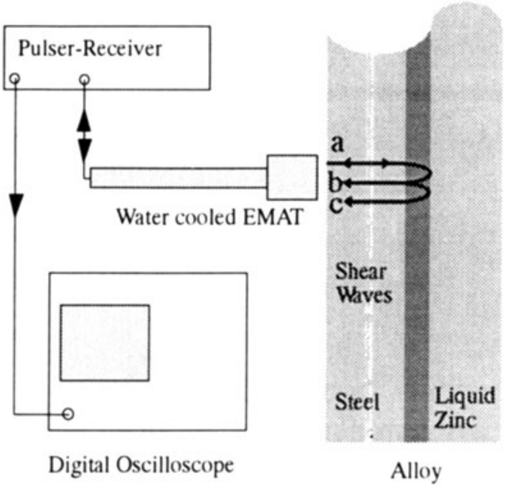

Figure 1. Test set-ups for galvanising tank.

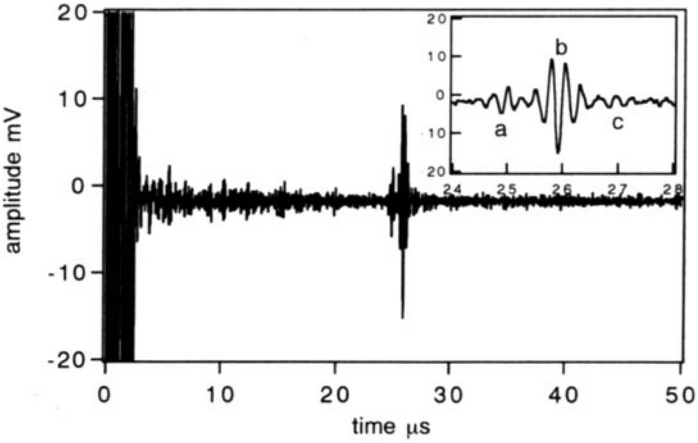

Figure 2. Typical waveform (100 averages) obtained from the galvanising tank. a, b, c are echoes arising as illustrated in Figure 1.

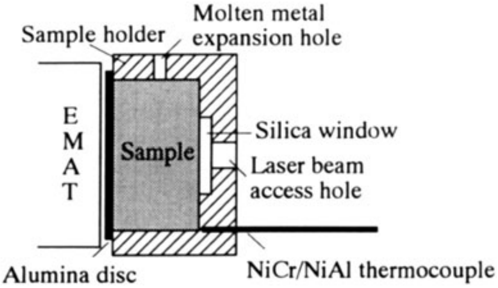

Figure 3. High temperature sample cell for melting experiments.

mild steel wall as the reaction proceeds and ideally the wall thickness should be regularly monitored to ensure the safety of the system. The galvanisers would prefer that the wall thickness of the tank should be measured while it still contains the molten zinc at elevated temperature and without any attempt to remove the dross layer that has accumulated.

We have demonstrated that the various interfaces can be detected with the SH shear wave EMAT acting as both generator and receiver and the thickness of the mild steel tank wall measured to better than 1mm. The experimental arrangement is shown in Figure 1 where the water cooled EMAT is less than 1mm away from the wall. A typical waveform recorded on a tank wall that was nominally 50mm thick when new is shown in Figure 2. This is an average taken over 100 shots. The repetition rate of the send receive EMAT was a few kHz so each measurement took less than 1 second. Clear echoes are seen arising from both the mild steel/alloy and alloy/molten zinc interfaces. The latter has the highest amplitude due to the larger acoustic impedance mismatch between the semisolid alloy and the molten zinc. There is also a hint of a third detected pulse which probably arises from an ultrasonic echo within the alloy layer.

Taking into account the temperature gradient across the mild steel wall and the temperature dependence of the velocity of the shear waves we can estimate the thickness of the wall from this particular tank to range from 37 to 39mm. Corrosion has obviously occurred but provided this thickness is maintained throughout the tank wall the plant is still safe to operate.

MEASUREMENT OF THE MELTING OF METALS

We have demonstrated that a pulsed laser generator/EMAT detector can be successfully used to ultrasonically monitor the properties of metals as they melt. This is of particular interest in the use of thixoforgable alloys where the velocities of the longitudinal and shear waves can give useful information on solid/liquid fraction present at any moment during the melting process. We have designed an ultrasonic cell that

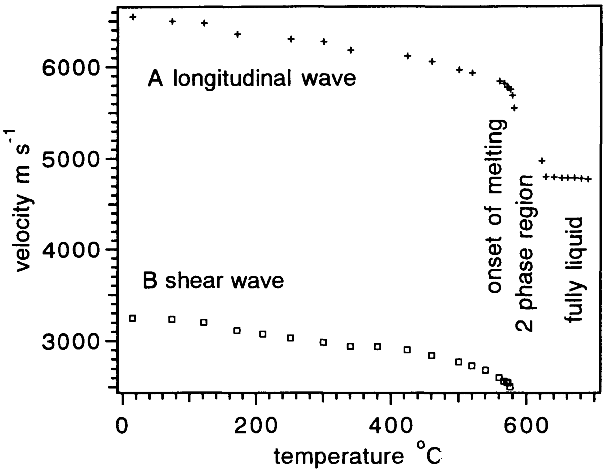

Figure 4. A: longitudinal wave, B: shear wave velocity for Al 4.86% Si binary alloy.

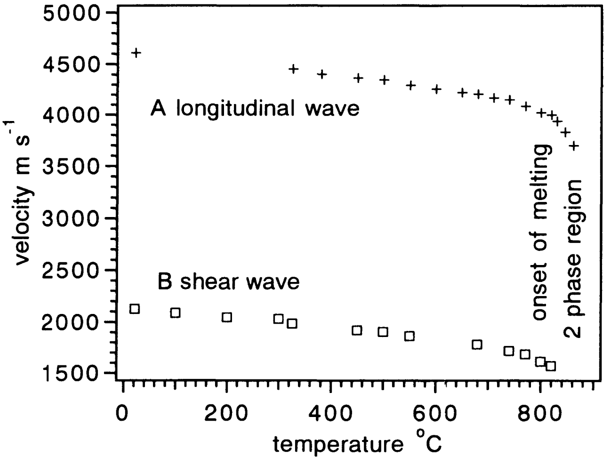

Figure 5. A: longitudinal wave and B: shear wave velocity for Cu 10.2% Si binary alloy.

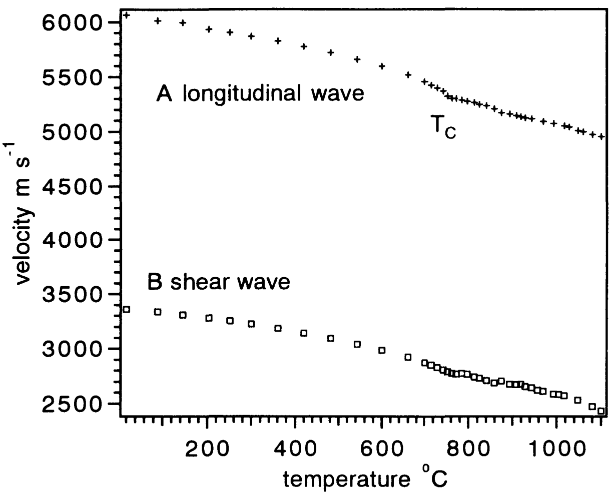

Figure 6. A: longitudinal wave velocity and B: shear wave velocity for thixoforgable tool steel, Tc is the magnetic Curie temperature

contains the thixoforgable alloy and maintains its geometry during the melting process (Figure 3). The pulsed Nd:YAG laser used for generation is incident on the surface of the sample through a silica window on one side of the sample while the EMAT receiver is brought into close proximity with an alumina disc on the other side.

The laser is focused so that the source is close to the threshold for ablation so that both shear and longitudinal waves are generated. The EMAT, although designed principally for shear waves is sensitive to both acoustic modes. We have carried out measurements on a Al 4.86% Si alloy, a Cu 10.2% Sn alloy and on tool steel all of which behave thixotropically while melting. Temperature dependence of the shear and longitudinal wave velocities are shown in Figs. 4 and 5 for the aluminium and copper based alloys. In the former case the longitudinal (L) wave can be monitored through the two phase melting region into the liquid phase (Figure 4A) while the shear (S) wave disappears very rapidly above 575°C (Figure 4B) where the sample is more than 50% liquid. The situation is rather different in the case of Cu 10.2% Sn. The longitudinal velocity decreases rapidly at the onset of melting at 830°C and disappears at 862°C (Figure 5A). The shear wave disappeared with the onset of melting (Figure 5B).

We have so far only taken the tool steel up to 1100°C, again using laser generation and EMAT detection to monitor the (L) and (S) waves (Figure 6). As the waveforms in Figure 7 show there are still appreciable echoes at the highest temperature and the construction of the new furnace should allow us to take this material through into its molten phase.

One interesting result that was observed when studying steels at high temperature concerned the measurement of mild steel. Figure 8 shows waveforms obtained in the ferromagnetic phase at 750°C, close to the Curie Temperature at 760°C and in the

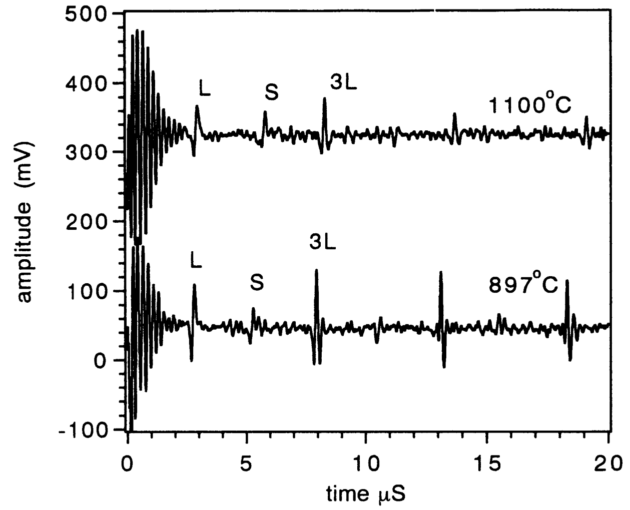

Figure 7. High temperature wave forms for tool steel.

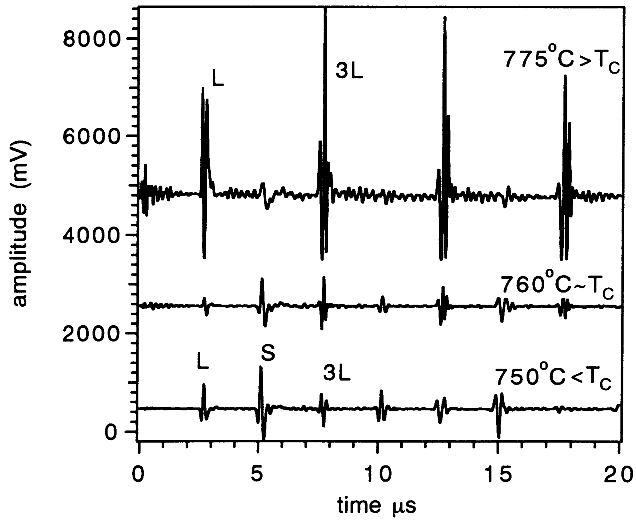

Figure 8. Waveforms for mild steel showing localised sensitivity enhancement just above the Curie point.

paramagnetic phase at 775°C. There is a striking enhancement of the longitudinal wave signals and a similarly marked reduction in the shear wave signals in the high temperature phase. The origin for this behaviour must be magnetic and probably associated with the change in sensitivity of the EMAT and warrants further work to elucidate.

HAND HELD LASER/EMAT SYSTEM

The availability of miniature pulsed Nd:YAG lasers together with the reduction in size achieved with the latest permanent magnet EMATs makes the construction of a hand held laser/EMAT system feasible. Such a system is shown in Figure 9 where the Q-switched Nd:YAG laser produces a 24 mJ pulse with rise time of ~ 10ns and a repetition rate of 1Hz, without water cooling. The EMAT is designed with a hole down the centre so it can be positioned concentric with the laser beam. A lens assembly in the beam delivery system ensures that the focus is adjusted for either thermoelastic or plasma generation.

We report here the results of an exercise to optimise the performance of such a system where the EMAT is again designed for the reception of radially polarised shear waves. Optimisation included a study of EMAT stand-off, the choice of energy density on the sample surface, the elimination of interference from surface waves and any plasma blast wave and improvements to the receive electronics particularly to minimise the dead time whilst maintaining optimum signal to noise in the remainder of the echo train. The aim was to use the system in single shot mode on pipework of interest to the oil industry.

The optimised thermoelastic waveforms on 20mm thick samples of aluminium and mild steel are shown in Figure 10A where the dead time can be seen to be less than 2μs and the shear wave echoes are the major feature in the trace. The shear waves have advantages for thickness measurement since they travel at half the speed of the longitudinal waves and therefore provide maximum separation from the dead time even on thin samples. There is some evidence, particularly in the aluminium trace of a mode converted longitudinal signal but this is rather weak. To demonstrate the effect of increasing the energy density on the surface Figure 10B shows a partially focused, weak plasma, source on an aluminium and steel sample. We now generate both longitudinal and shear waves, the dead time is increased and the signal to noise in the remainder of the echo train has significantly deteriorated.

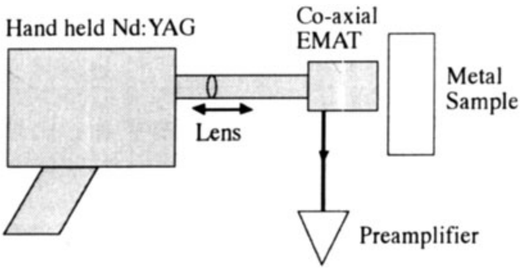

Figure 9. Hand held send-receive laser-EMAT system

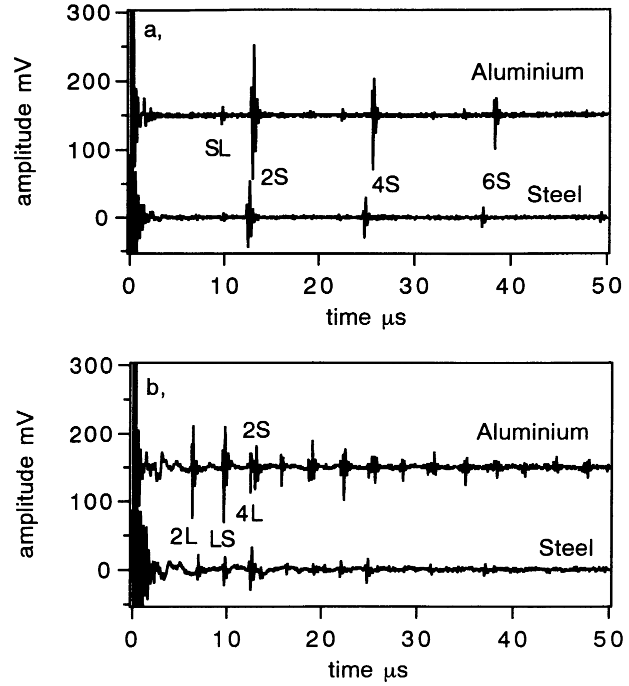

Figure 10. A: optimised thermoelastic waveforms, B: complex waveforms produced by weak plasma source.

CONCLUSIONS

Lasers and EMATs both have a role to play in both non contact generation and detection of ultrasound. It is important that the appropriate combination is chosen for a particular application bearing in mind the overall cost, the industrial environment, the acoustic mode required, the repetition rate, the ultrasonic bandwidth amongst a range of important parameters.

ACKNOWLEDGEMENTS

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