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PROPAGATION OF ULTRASONIC ENERGY THROUGH SOLIDIFYING CAST STEEL AND CAST IRON

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Measurements of elastic constants, ultrasonic attenuation and velocity for steel have been reported at elevated temperatures.[1-4] The solidification of steel has been widely reported[5-11] and Kurz and Lux[4] have carried out attenuation measurements with various materials and have suggested a model for measurements with steel up to 1500°C, stating that the solidification mechanism could be determined by transmission or pulse echo techniques. This report discusses experiments which have been carried out on the transmission of ultrasonic energy through cast steel and iron during solidification.

The amount of energy and the velocity of ultrasound which is transmitted will depend on the structural changes which occur in the solidifying material at any specific temperature during this period. In cast steel this transmitted energy is likely to be affected by grain growth in the liquid steel, grain orientation, phase changes and flaw formation. In cast iron it is common experience that the ultrasonic velocity and attenuation of solid spheroidal graphite irons are different from those in flake graphite irons. It is therefore reasonable to suppose that if the amplitude of ultrasonic energy passing through iron as it solidifies is monitored, variations will be apparent that will depend upon the graphite form in the final material.

FIRST TRIAL: EXPERIMENTS ON CAST STEEL

Experimental Procedure In order to introduce ultrasound into the liquid steel, a probe system was designed. The device consists of: Stand-off bar - A copper cooling coil - A probe holder

The casting which was 4 in (100 mm) square x 6 in (150 mm) long and weighed 30 lb (13.6 kg) was produced in a sand mould. Liquid steel was melted in a high frequency furnace and two thermocouples were positioned in the mould in order to measure the cooling rate. The ultrasonic device, with a 23 mm diameter 2½ MHz longitudinal probe, was positioned in the mould. The pulse echo system was used and changes in ultrasonic attenuation were measured by ensuring that the height of the first back wall echo was kept at a constant value by use of the calibrated attenuator. Fig.1.

Before pouring liquid steel into the mould, the ultrasonic equipment was calibrated by using the echo from the end of the stand-off bar. After pouring, this echo disappears due to fusion of the end of the bar, this ensures transmission of ultrasound into the liquid steel. A separate echo, from the liquid steel/sand interface 4 in (100 mm) away from the end of the stand-off bar, reappears on the screen. This echo is brought to a specific height on the screen, attenuator, time and temperature readings were taken during the cooling of the steel block.

Results. Fig. 2 is a normal cooling curve of temperature against time for a 0.3% carbon steel. From the graph, it can be seen that the cast block solidified in approximately 5 minutes, it reached a temperature of 850°C in 30 min and in approximately 60 min it reached 700°C, which means that it was fully ferritic. From Fig.3, which shows the relationship between the attenuation and temperature, it is evident that good transmission (low attenuation) occurs through liquid steel but this result rapidly changes and, at 1500°C, transmission is low (attenuation high). The back echo is completely lost due to the scattering and absorption of the ultrasonic beam by the cast structure from 1500°C to 700°C. At 700°C, the echo returns quickly and persists to room temperature.

The ultrasonic pulse echo technique with a 2½ MHz longitudinal probe was used for this trial. Since no back echo could be obtained from 1500°C to 700°C it follows that any flaws which may form during this temperature range would not be detected.

Conclusions to the First Trial -

1. The liquid steel wets the end of the stand-off bar, ensuring good coupling with consequent transmission of ultrasonic energy.
2. Owing to the small volume of liquid steel used, rapid changes, which were difficult to follow, occurred in the initial stages of solidification.
3. High ultrasonic attenuation occurred and the back echo completely disappeared when using the pulse echo technique at 2½MHz frequency in the temperature range 1500°C to 700°C. Flaws would not be detected in this temperature range.

A second series of trials was arranged involving the use of 4 cwt (0.2 tonnes) of liquid steel (the capacity of the Junkers Furnace at the Research Association) and the transmission technique with ½ MHz probes. The reason for the changes were two-fold: firstly, this amount of steel would cool relatively slowly, enabling more reliable results to be obtained, and secondly, a lower frequency (½ MHz) and the transmission method would overcome some of the attenuation problems encountered in the initial trial.

SECOND TRIAL: CAST STEEL

Experimental Procedure A pattern 12 in (300 mm) x 16 in (400mm) long was used to produce a mould cavity. The transmitted pulse is affected by changes in attenuation, which are measured by recording the calibrated attenuator values required to keep the pulse at a given height on the screen. 4 cwt (0.2 tonne) of liquid steel was poured into the mould cavity and readings taken as described above.

Two types of steels were examined, a .45 C steel and a 18% Chromium 12% Nickel austenitic steel. A .3 carbon steel was also examined in order to assess the possibility of predicting the formation of a shrinkage cavity during solidification; in this experiment two sets of probes were placed in the mould, one pair at the bottom of the mould and one pair close to the head where a cavity would be expected. (Fig.4)

The .3 Carbon and 18/12 Austenitic Steel

The results of these experiments are shown graphically in Fig. 5 the relationship between ultrasonic attenuation and time is plotted for a ferritic .3 carbon steel and an austenitic steel. The difference in the shape of these curves is caused by the transformations which occur during the cooling of the liquid metal to room temperature.

The .3 carbon steel undergoes a series of structural transformations during cooling. These changes are molten steel, liquid and austenite, austenite and ferrite, ferrite; each of these transformations is accompanied by a change in ultrasonic attenuation. The austenitic steel does not undergo the same transformations during cooling, from the liquid steel, trans -

formation occurs to austenite, this structure is unchanged to room temperature: the ultrasonic attenuation: time curve agrees with this structural transformation.

Flaw Formation A .3 carbon steel was used to show the effect of flaw formation on the transmission of ultrasound. Probes were positioned in the 12 in (300 mm) x 16 in (400 mm) pattern. One pair placed diametrically opposite where a cavity would not form, and a second pair beneath the feeding head where a shrinkage cavity would form. The result is shown in Fig.6. The two attenuation curves, although following a similar pattern, do show significant differences. The lower probe system (sound material) shows a classical curve which has been described earlier, the .3 carbon steel in Fig. 5. The curve plotted from the attenuator readings of the upper probes (unsound material) could be used to predict the formation of a shrinkage cavity whilst the steel is still liquid. During the cooling to room temperature, phase transformations are still detected but the strength of the pulse which is received by the probe is reduced due to the formation of the cavity. Fig. 7.

Velocity Measurements The results of the velocity of sound transmitted through liquid and solidifying steel is shown in Fig. 8, the results are in agreement with other published work.

EXPERIMENTS ON CAST IRON

An initial experiment was carried out with the Smiths Mark 7 ultrasonic equipment using an external calibrated attenuator to measure the relative amplitude of the transmitted pulse. Further experiments were carried out using the ultrasonic generator and monitoring system designed oringinally for sub-surface defect detection. The transmitted energy is passed through tuned amplifiers and the energy in the first transmitted pulse isolated by an electronic gate. This energy is passed through an integrator, and the output recorded on one track of a pen recorder. A second pen is connected directly to a thermocouple which has its sensing element between the ultrasonic stand-off bars. The recorded trace therefore shows transmitted intensity and temperature of the metal.

Liquid cast iron is poured into the mould and allowed to cool, the results are shown graphically in Fig.9 and 10 of two types of iron, a white and a grey cast iron.

Discussion White irons and grey irons show recognisable different patterns which must be associated with the deposition of the graphite. The changes in the pattern do not always correspond to the phase changes revealed by the temperature measurements, although it is recognised that the temperature recorded by the thermocouple is not necessarily following that of the metal near the probes, since the probes provide a considerable heat sink. Blocks have been sectioned through the probes, but no evidence of chilling has been seen.

Conclusions A technique has been developed which enables phase changes in solidifying cast steel, and deposition of graphite and phase changes in solidifying cast iron to be followed using ultrasonic methods. It may be possible, therefore, to predict the final structure of the metal by assessing the ultrasonic changes which occur during cooling. Further research work is required into this important subject.

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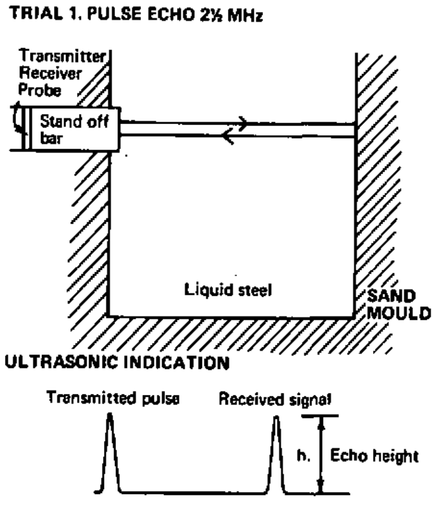

Fig.1

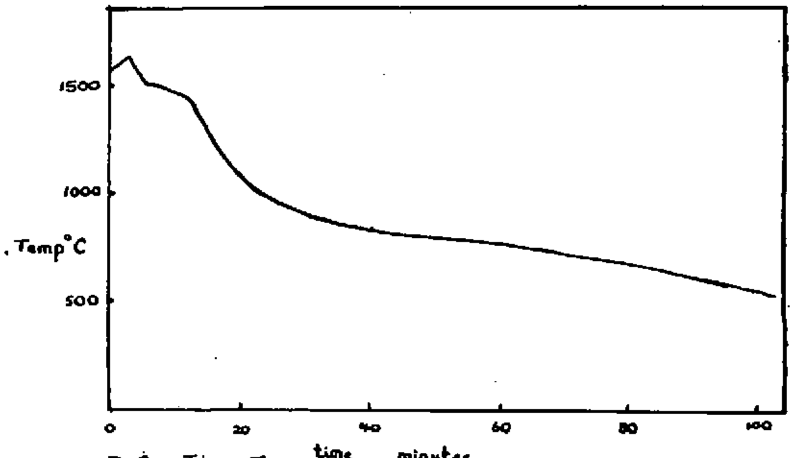

Fig 2 Time - Temp° Curve for Steel

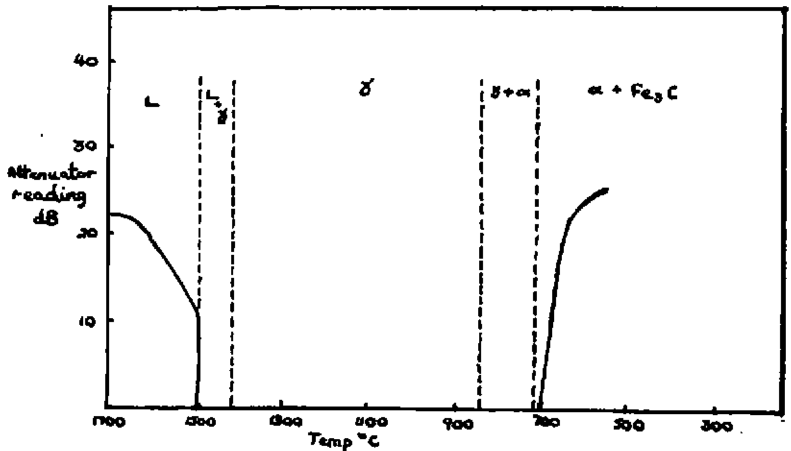

Fig 3 Typical Solidification Curve

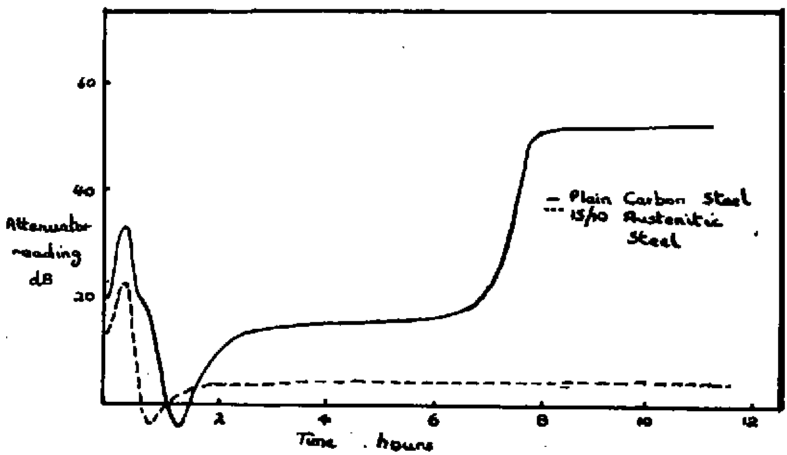

Fig 5 Typical Curves for Carbon and Austenitic Steels

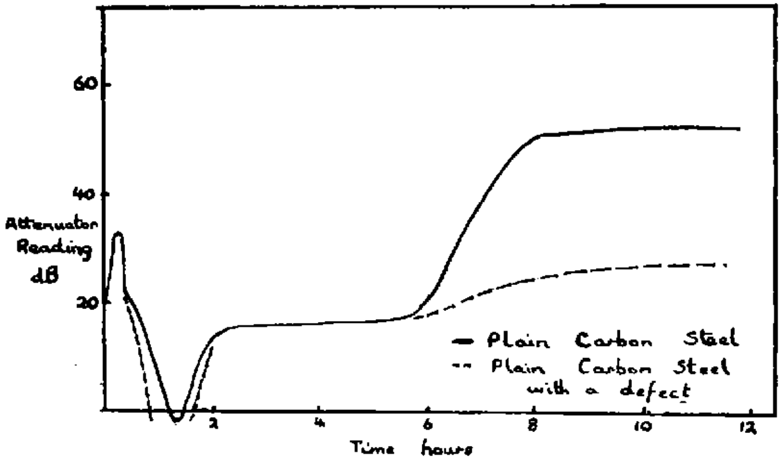

Fig 6 Effect of Shrinkage Cavity on Ultrasonic Transmission

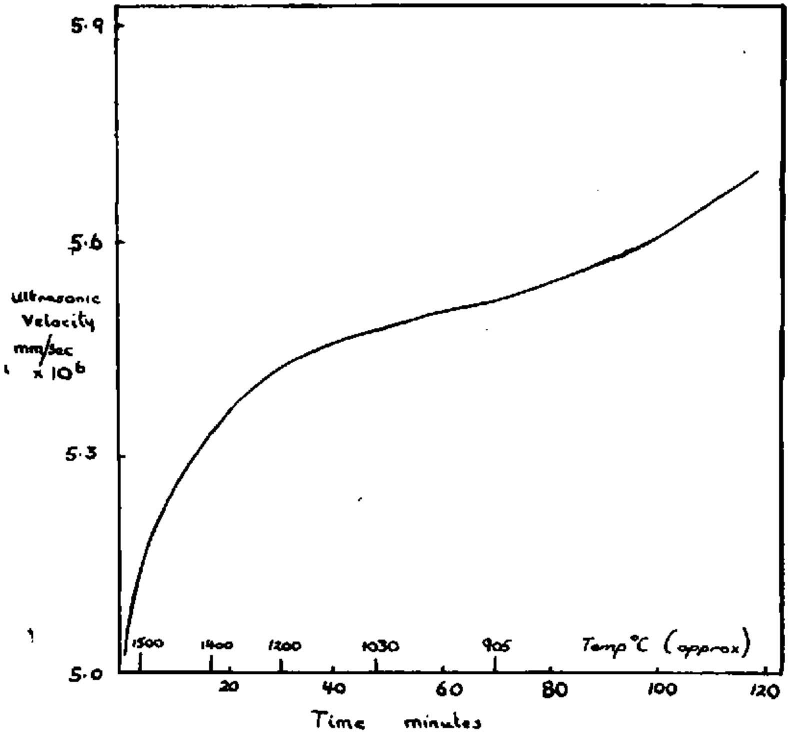

Fig 8 Time - Velocity Curve for Steel

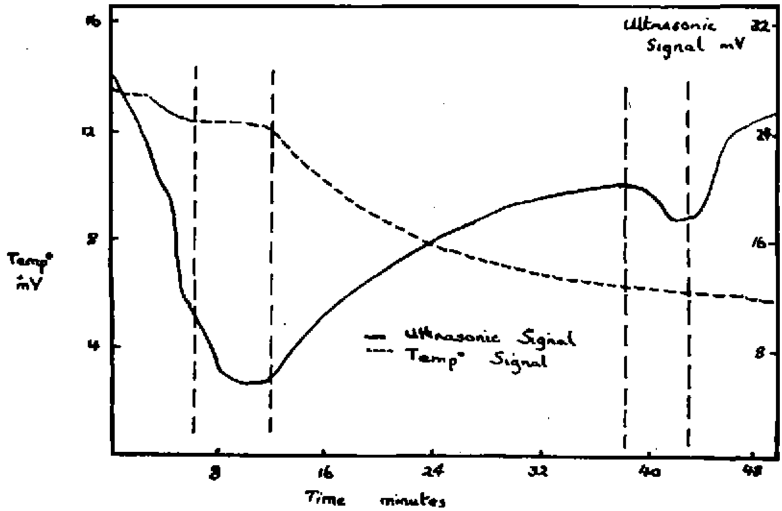

Fig 9 Solidification of White Iron

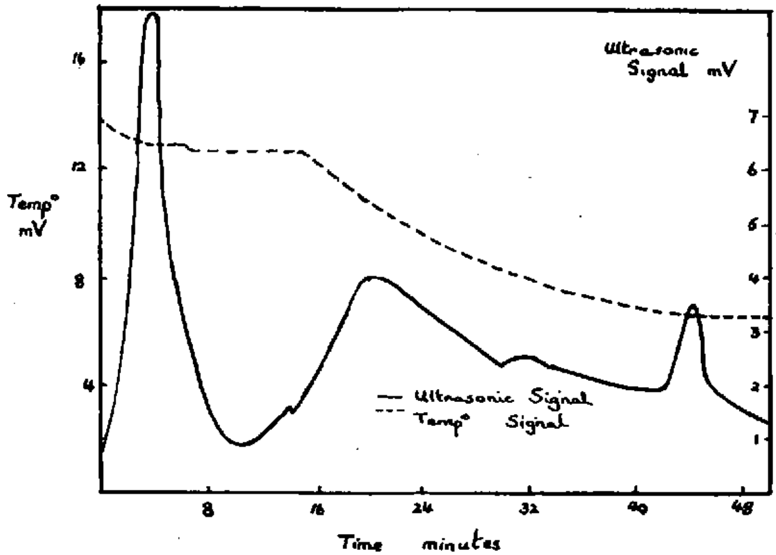

Fig 10 Solidification of Gray Iron

TRIAL 2. TRANSMISSION ½ MHz

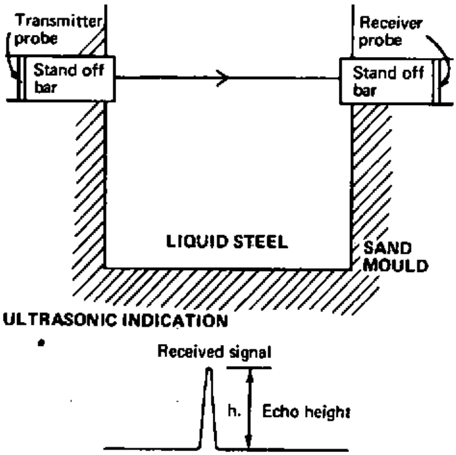

Fig. 4.

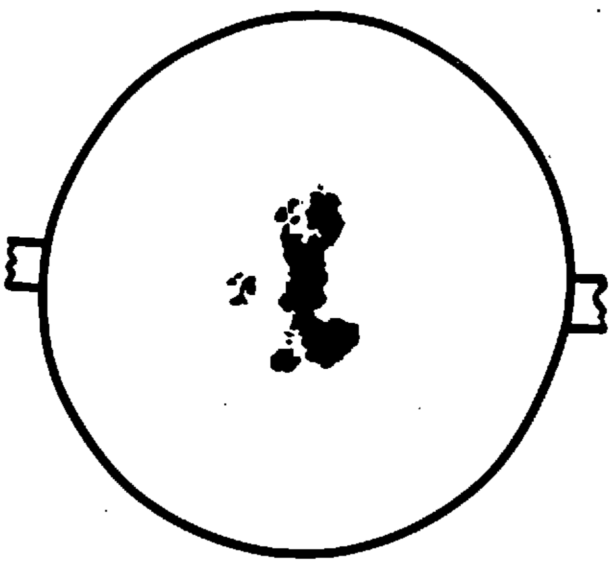

Fig. 7.