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NON-DESTRUCTIVE EXAMINATION OF FLAT BONDED RUBBER MOUNTINGS

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Non-Destructive Examination of Flat Bonded Rubber Mountings

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SUMMARY

The use of bonded rubber mountings has become widespread in many engineering fields. However, some limitations are imposed upon the allowable stresses in designs because of possible bond imperfections from which early failure may result.

This report is concerned with the application of ultrasonic techniques to the detection of flaws inside flat bonded rubber mountings. Experiments are described upon flaws at a bond and in the bulk of the rubber itself using transmission of ultrasonic waves.

INTRODUCTION

The need for a non-destructive method of testing the bonds of a rubber-to-metal welded component has been realised for some time. Rubber mountings are used in heavy duty applications in aircraft, automobile and locomotive engineering and in many other cases. If these units can be tested without damage to ensure that the rubber has no voids in it and that the bonding is complete, then the ultimate life of the mounting can be expected to be greater. No previous attempt to investigate the perfection of rubber to metal bonding has been published although reference has been made to the use of ultrasonics[1] for this work. With respect to voids inside rubber, it has been reported[2] that flaws inside a tyre could be detected by recording the non-transmission of ultrasonic waves. This investigation covers the transmission of ultrasonics through a mounting with flat metal surfaces. Flaws at the bond interface and in the rubber itself were explored for rubber of gum and black compositions when the component under test was strained.

PRINCIPLES OF FLAW DETECTION BY ULTRASONICS

It is not proposed to give a comprehensive account of ultrasonic flaw detection principles here, as there are several accounts available.[3 4 5] It will be sufficient to recall that ultrasonic energy transmitted into a solid medium from one boundary, shows the usual properties of rectilinear propagation of wave motion when the dimensions concerned are large in comparison with a wave length, and also shows the usual diffraction behaviour at slits and at the edge of reflecting surfaces. Flaws large enough to reflect an appreciable amount of energy can be detected by the echo so produced or by the shadow cast on the further boundary.

The echo method is the one most used in detecting flaws in metals, but a difficulty arises in applying this method to rubber-to-metal bonds, as the echo from a sound bond is very strong and the echo from a bad bond not much stronger, and in practice the small difference is obscured by small variations in the intensity of the transmitted and received wave due to the irregularities in the metal surface to which the ultrasonic probes must be applied.

For this reason the shadow method has been exclusively employed. This requires the application of the transmitter to one metal plate of the component, with the receiver on the other metal plate, facing the tran: mitter as shown in Fig. 1. With this arrangement the ultrasoni vibrations must pass from the metal to the rubber, and then from th rubber into the metal, suffering a great reduction of intensity at eac interface. However, within wide limits the loss in energy can be mad good by amplification of the received signal. When a surface with a ba bond is interposed this signal suffers a marked reduction in intensit When the dimensions of the region of bad bonding are large in compariso with the wavelength of the ultrasonic wave energy the shadow is complete.

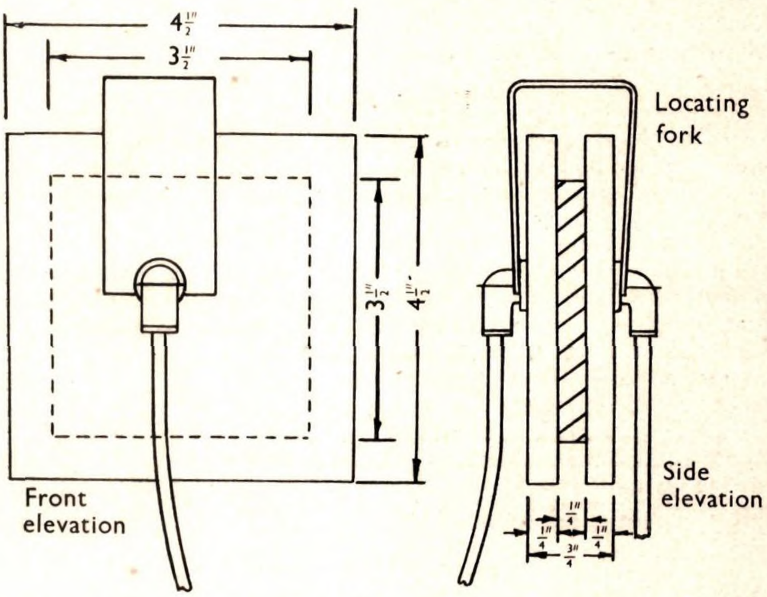


Fig. 1.
Dimensions of flat bonded sandwich
and arrangement for aligning quartz probes.

When the dimensions approach the order of magnitude of a wavelength or less, as in this work, then some energy will be diffracted into the shadow, and the signal may be quite appreciable over the whole area of the shadow. In this case there is a second effect which is an aid in assessing the presence and size of the flaws. The diffracted signal arrives *later* than a signal transmitted straight through from one side to the other. In the case of a flaw 1 cm. in diameter, the signal arrives late by about $\frac{1}{3}$ of a microsecond. If the test is carried out at a frequency of 2.5 megacycles per second, the duration of half a cycle is only 1/5 of a microsecond. It is possible to see a shift of a fraction of a wave while testing.

Description of Apparatus and Specimens

Ultrasonic Equipment.

The transmitter-driver and receiver-amplifier system was supplied by Glass Developments Limited and resembles in all essential respects the corresponding equipment incorporated in their ultrasonic flaw detector, the Ultrasonoscope. The oscilloscope employed was a piece of surplus Government equipment known as the Type 73 Test Set.

The transmitter-driver employed a thyratron capable of an output voltage between one hundred and three hundred volts, according to the size and type of the various transducers employed. In order to make the transmitted pulse as short as possible no electrical filter was used. The receiver amplifier had a gain of 100,000 within 3db. between 0.5 and 2.5 megacycles but was never used at full gain.

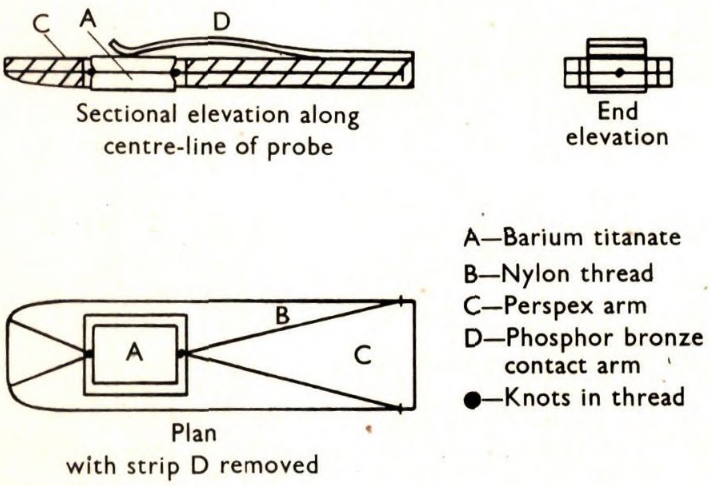
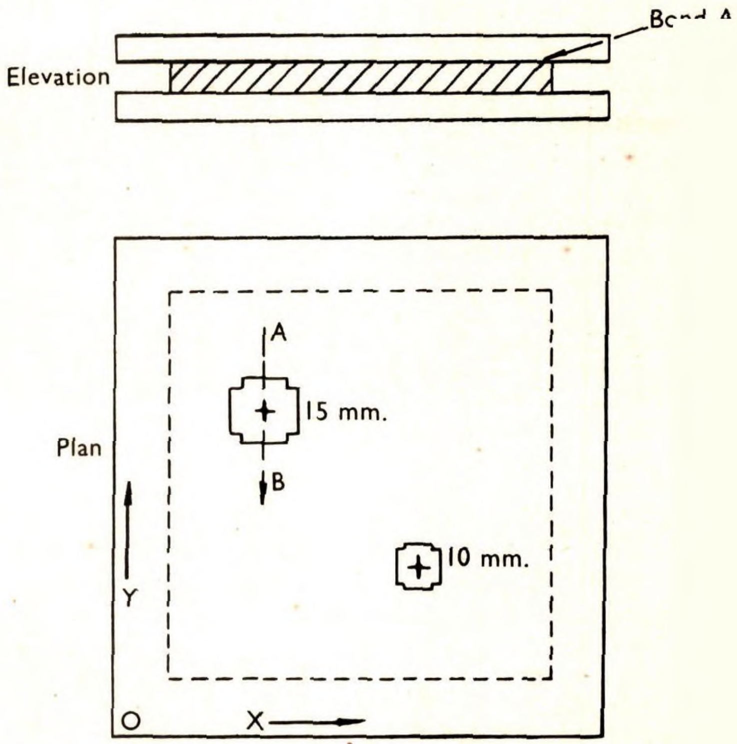


Fig. 2.

Diagram of small probe using silvered barium titanate

The first experiments were carried out with quartz crystals one cm. in diameter for the transmitter and the receiver and the results were satisfactory. However, the margin between signal and noise was so small that work with thicker samples would have been difficult. In addition it was desirable to employ a receiver probe smaller than one cm. in diameter, and tests have been carried out using barium titanate for the transmitter and the receiver, due to the much higher signal level obtainable with this material, other factors being equal.

With both materials difficulty was experienced due to the silver electrodes rubbing away during the "scanning" of the test-piece. This trouble was overcome by clamping the barium titanate disc 2.3 cm. in diameter between the flat ends of co-axial cylinders of duralumin about 1 in. diameter and 1 in. long. This assembly was not only very robust, but gave the incidental advantage of additional damping to the barium titanate which, in turn, made the pulse shorter and sharper.



Positions of 3mm. × 2mm. Barium Titanate Probe where Faults were Recorded in Ultrasonic Test.

Centre of Fault of Diameter Stated Made in Bond A,

Fig. 3.

Ultrasonic test on bond flaws in a flat bonded sandwich.
(Lamp black mounting compound)

For some purposes a small exploring probe is valuable. Fig. 2 shows a probe in which the active area was 2 × 3 mm. the thickness being 1 mm. This probe has been used in two principal ways. The assembly described in the previous paragraph was used as a transmitter and irradiated an area about 1 in. diameter. The small probe was then used to make a fine scan of this area and the transmitter then shifted to an

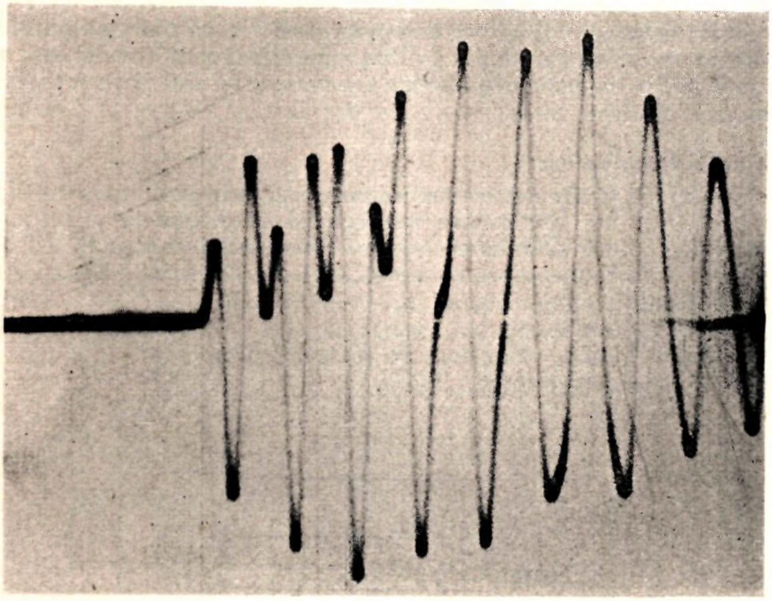


Fig. 4a.

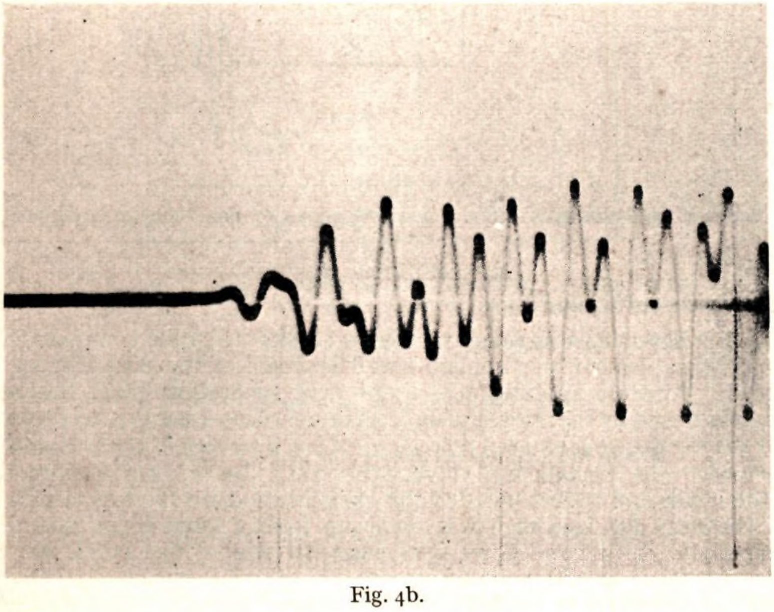


Fig. 4b.

Oscillograms for Transmission of Ultrasonic Waves through Bonded Rubber Samples. (a) No Flaws; (b) Probes over a Flaw in the Specimen.

adjacent area and the fine scan was repeated. The alternative method involved the fixing of the small probe opposite the centre of the transmitter by means of a fork similar to that shown in Fig. 1, which permitted the scanning of the sample by moving the transmitter and receiver together over its surface.

Bonded Rubber Specimen.

The details of the flat bonded rubber sandwich used in the tests are shown in Fig. 1. The rubber was bonded to the metal plates by a cement and rubber solution technique. The steel plates projected over the sides of the rubber block by ½ inch so that wedges could be tapped in between them to provide separation strains of up to 10 per cent. The flat faced holders containing the quartz crystals were coupled together mechanically by a locating fork so that they were always in line and normal to the explored surface, Fig. 1.

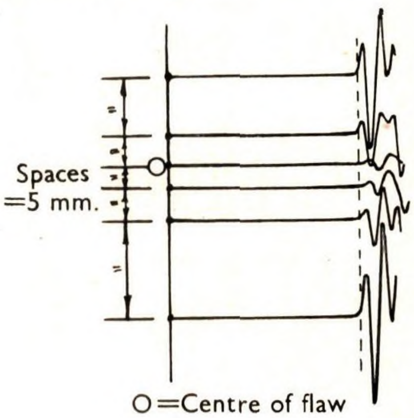


Fig. 5.

Series of oscillograms at different positions across 15 mm. diameter bond flaw.

Experimental Results

Investigation of Bond Flaws.

A flat specimen was prepared from a black inner tube compound and the bonding cement was applied over the whole of the area covered by rubber. After the application of a 7 per cent. separation strain, the specimen was tested by the transmission of ultrasonic waves using quartz crystals and the oscillograms showed no regions of low intensity of the transmitted wave when the crystals were traversed over it. Later visual examination of the bonds and rubber block of this specimen did not disclose any flaws.

The next flat specimen was made up from a lamp black mounting compound. Two large flaws were made at one of the bonds by not covering the areas with bonding cement, Fig. 3. The specimen was tested unstrained using the barium titanate transducer and no flaws were detected. A 10 per cent. separation strain was then applied and the two bond flaws were detected, as shown in Fig. 3.

This specimen was the one used in preparing the results shown in Figs. 4 and 5 which show the most important features of this method of detecting flaws. The oscillograms of Fig. 4 are photographic reproductions. The first peak of the trace is the part of the signal which is most significant. The later part of the trace consists of a heavily damped

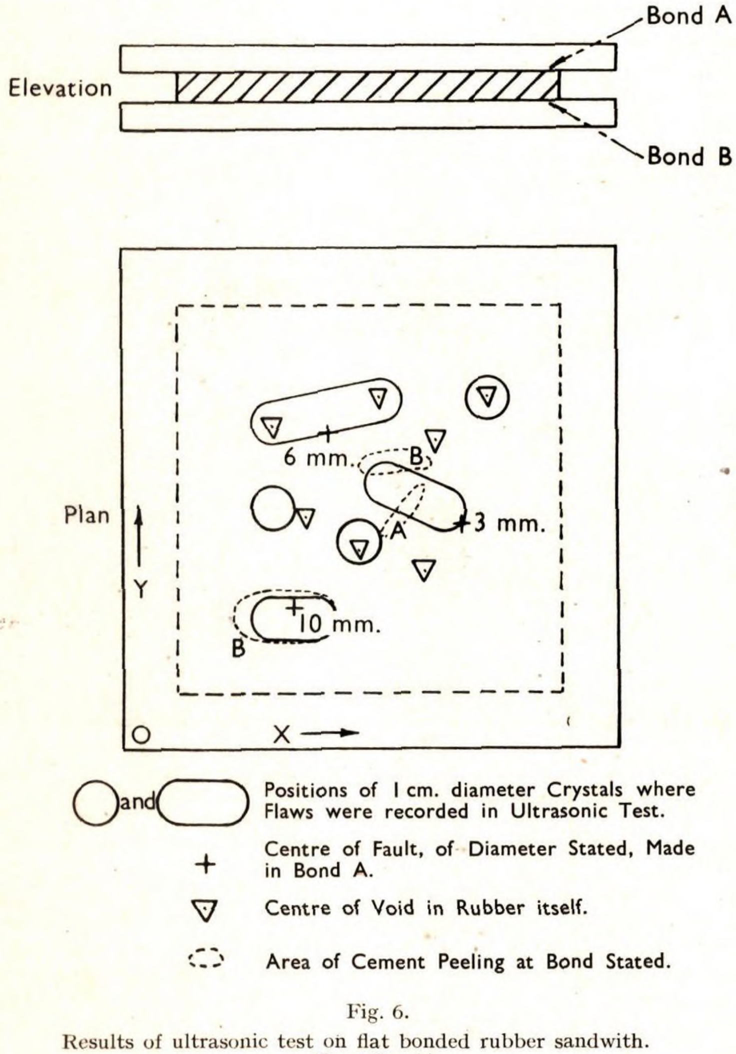


Fig. 6.
Results of ultrasonic test on flat bonded rubber sandwith.
(Gum Stock).

train on which is superimposed complex multiple reflections. Fig. 4a shows the direct transmission at a point 2 cm. below the centre of the 15 mm. diameter flaw, while Fig. 4b is the result obtained at the centre of the flaw. It should be specially noted that the amplitude of the first peak is much more affected by the presence of the flaw than is the case for the multiple reflections.

In order to bring out the influence of the flaw on the time of arrival of the first peak, Fig. 5 shows a series of tracings of oscillograms made at intervals of 5 mm. along the line AB across the 15 mm. diameter flaw in Fig. 3. The shift to the right as the centre of the flaw is approached and the signal has to travel around the flaw, can be clearly seen. When the oscilloscope is viewed directly the trace moves to the right and back again as the flaw is traversed and so the shift is even more obvious.

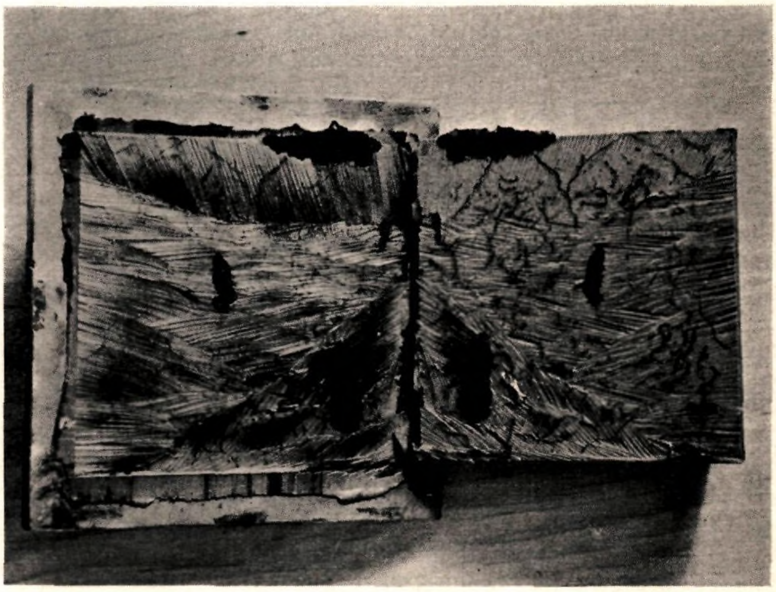


Fig. 7.

Peeling of Cement at Bond B of Flat Rubber Sandwich.

Extension to Voids in the Rubber.

The third flat specimen which was tested, was made up from a sulphur cured gum compound with M.B.T. accelerator. Three flaws of different sizes were made at one of the bonds as shown in Fig. 6. In addition, the rubber put into the mould was cut from stored compound and was not remilled to induce the formation of voids in the rubber. The specimen was separated by a 10 per cent. strain and left for several weeks before testing.

The positions of the quartz crystals corresponding to the oscillogram showing a flaw in the specimen were measured with reference to the axes OX and OY to the nearest $\frac{1}{2}$ cm. The result of the traverse is given in Fig. 6 and compared with the result found in the rubber during later examination. The voids in the rubber lay in three dimensions so it was impossible to record their exact positions, but the centres of the voids are shown in Fig. 6. It was found in this specimen that peeling of the bonding cement had taken place at both plates during the period the specimen had been under strain, and the peeling at bond B is shown in Fig. 7. The peeling of the bonding cement at the edges of the sample was not noted during the ultrasonic test.

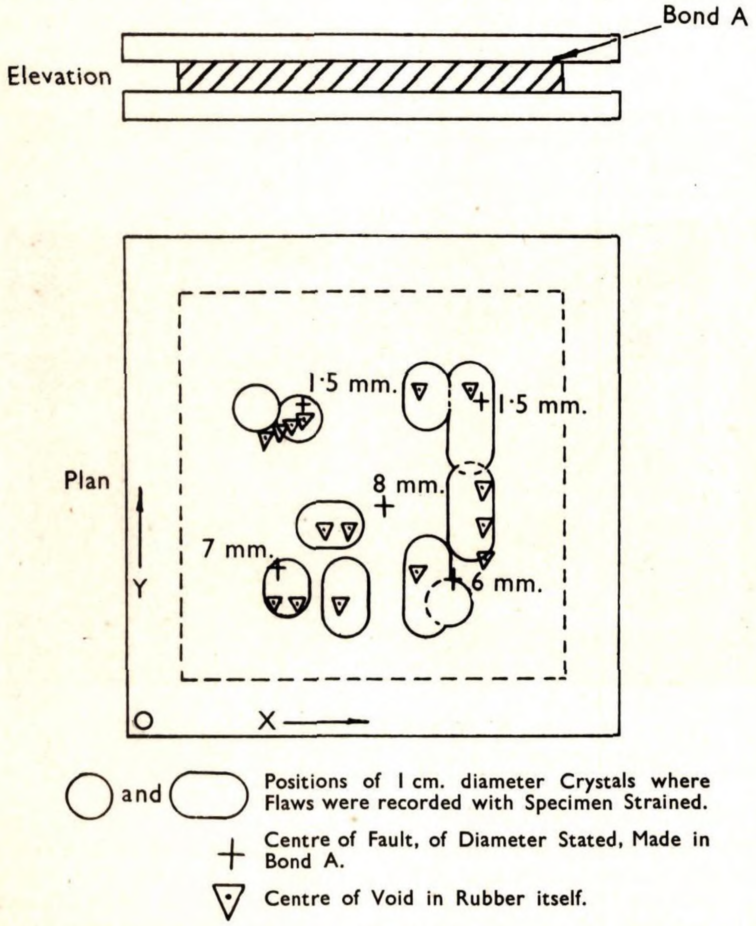


Fig. 8.
Results of ultrasonic test on flat bonded rubber sandwich.
(Gum stock).

A specimen of a second gum compound with Santocure accelerator and sulphur cured was tested next and again the rubber was from stored compound and not remilled before moulding. Five flaws were made at one of the bonds, as shown in Fig. 8. With the specimen in the unstrained condition, no significant variations were observed in the oscillograms. A 10 per cent. separation strain was then applied and the results observed are shown in Fig. 8. Examination of the block of rubber taken from the specimen showed that the results recorded with the sample strained were accurate. A picture of the voids in the neighbourhood of the right hand portion of Fig. 8 is given as Fig. 9.

Discussion of Results

It was found during this investigation that complete flaws at a bond and voids in the rubber block could be detected with good accuracy by the transmission of ultrasonics as long as the specimen was strained. It was not possible to discriminate between different faults as there was no noticeable difference between the oscillogram for a bond flaw or that for a rubber flaw.

Fig. 9.

Voids in Flat Rubber Sandwich Detected by Transmission of Ultrasonic Waves.

The voids in the rubber were easily detected as long as they were not small in relation to the diameter of the crystals. Similarly the 1·5 mm. diameter bond flaws shown in Fig. 8, were not determined uniquely as these areas corresponded to voids in the rubber which were more serious than the small flaws. In the same specimen, the 8 mm. bond flaw was not found during the test, but it was situated at the centre of the specimen and as the plates bent slightly under the strain, the rubber and metal may not have been separated in that vicinity.

The application of a separation strain of only 10 per cent. to the specimen emphasises the non-destructive nature of the test. At present, it is impossible to distinguish between good and poor bonding unless the metal and rubber surfaces separate under stress when the corresponding area will be shown by the ultrasonic exploration.

Conclusions

Complete bond flaws and voids inside a flat bonded rubber specimen can be detected by the transmission of ultrasonic waves as long as the specimen is strained. The applied strain for the rubbers investigated was no greater than 10 per cent.

Future Developments

It is realised that the bulk of engineering rubber mountings do not have flat surfaces. Experiments on mountings having curved surfaces, namely rubber bushes, have been started although the type and magnitude of strain to apply to a bush in order that the rubber and metal may be separated, is not known at this stage.

Acknowledgements

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