10th JULY, 1913.

# EXPERIMENTS ON THE ELASTIC DEFORMATIONS OF AUTOGENOUS (OXY-ACETYLENE) WELDS AND OF WELDED DRUMS.

By

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The following paper contains an account of:—

A. Some experiments on autogenous welds produced by the oxy-acetylene blow-pipe.

B. The mode of failure of certain autogenously-welded steel drums.

C. An attempt to determine the relative strains on the shell surface of such drums when under pressure.

1. *Experiments on Autogenous Welds produced by the Oxy-Acetylene Blow-pipe.* The use of the oxy-acetylene blow-pipe for welding is now so common that a detailed description of it is scarcely necessary. The process has taken its place as one of the ordinary methods of producing autogenous welds—that is, welds made without the use of soldering material. It is often used instead of the processes of brazing and riveting, and has many applications in the constructive arts, although probably its most striking achievements have been in the direction of repair work.

The authors had the opportunity, a few years ago, to see a good deal of welding work done by a very expert operator, Mr. G. Kennedy, and of testing the value of some of the welds made by him; as there is not much in the way of data in connection with such welds, they thought it might be interesting to the members of this Association to have a few of the facts put before them.

2. *Short Description of the Welding Process.*—The apparatus required for welding is very simple, consisting of (1) a blow-pipe; (2) a cylinder of oxygen; (3) a reservoir of acetylene, or alternatively an acetylene generator of the ordinary type, together with (4) the necessary gauges and valves. The most convenient way of arranging the acetylene supply is to have it dissolved in acetone, under considerable pressure. The blow-pipe most commonly used was developed by Fouché, and appears to provide complete immunity from accidents due to the explosion of the acetylene and oxygen mixture. The thermal value of acetylene reaches the extraordinarily high value of nearly 1850 B.T.U. per cubic foot, and when burned in oxygen attains a temperature usually stated as 6300 F°. This is an advance on the oxy-hydrogen blow-pipe, of which the oxy-acetylene blow-pipe may be considered the lineal descendant, just as the former was of the ordinary blow-pipe, using air and gas. To burn one volume of acetylene 2½ volumes of oxygen are required, according to the following formula:—

$$2\,C_2H_2 + 5\,O_2 = 4\,CO_2 + 2\,H_2O$$

the resulting gases being carbon dioxide and water vapour. For the welding process, however, less of oxygen than this is supplied, so that the combustion is not complete, the process being usually represented by the equation

$$C_2H_2 + O_2 = 2\,CO + H_2$$

the gases here being carbon monoxide and hydrogen. The result is, in fact, a reducing flame rather than an oxidising one, and the risks of carbonisation and oxidisation of the metal to be welded are avoided. If the two pieces of metal to be welded are of small thickness, say, ¼ of an inch or less, the process can be carried out by bringing the two edges into contact and fusing them together without the addition of any extra metal. The longitudinal seams, in the case of the drums referred to in Part B of this paper, can be taken as cases in point. On the other hand, for thicker materials the edges are first bevelled and the joint is made by gradually melting a long iron or steel wire into the groove so formed and fusing the sides of the groove from point to point as the groove is filled by means of the molten wire. The welds referred to in the present part of the paper are of this nature, the wire used being soft Swedish iron. As the welding proceeds the junction line takes on a very characteristic appearance, usually termed "pooling" (see Fig. 2) on the outside where the blow-pipe works, while on the inside it exhibits usually an irregular rough surface, indicating the breaking through of the molten metal.

3. *Test Specimens welded by Mr. Kennedy.*—Amongst the examples of welds which Mr. Kennedy was good enough to make for us in the Mechanical Engineering Laboratory of the University, are those illustrated in Figs. 1 to 3.

The weld shown in Fig. 1 is that of an artesian bore tube 6 inches diameter and ¼ inch thick. The pipe was completely cut through at right angles to its length and was then welded together again. The appearance of the surface of the weld is shown in Fig. 2. The length of bore tube was then placed in a testing machine and subject to transverse pressure as a beam. This had the effect of causing it to collapse at the centre and to fracture in two or three places. The interesting point to note in connection with this is that one of the fractures extended right across the weld, but there were no signs of any fracturing of the weld itself in the direction of its length.

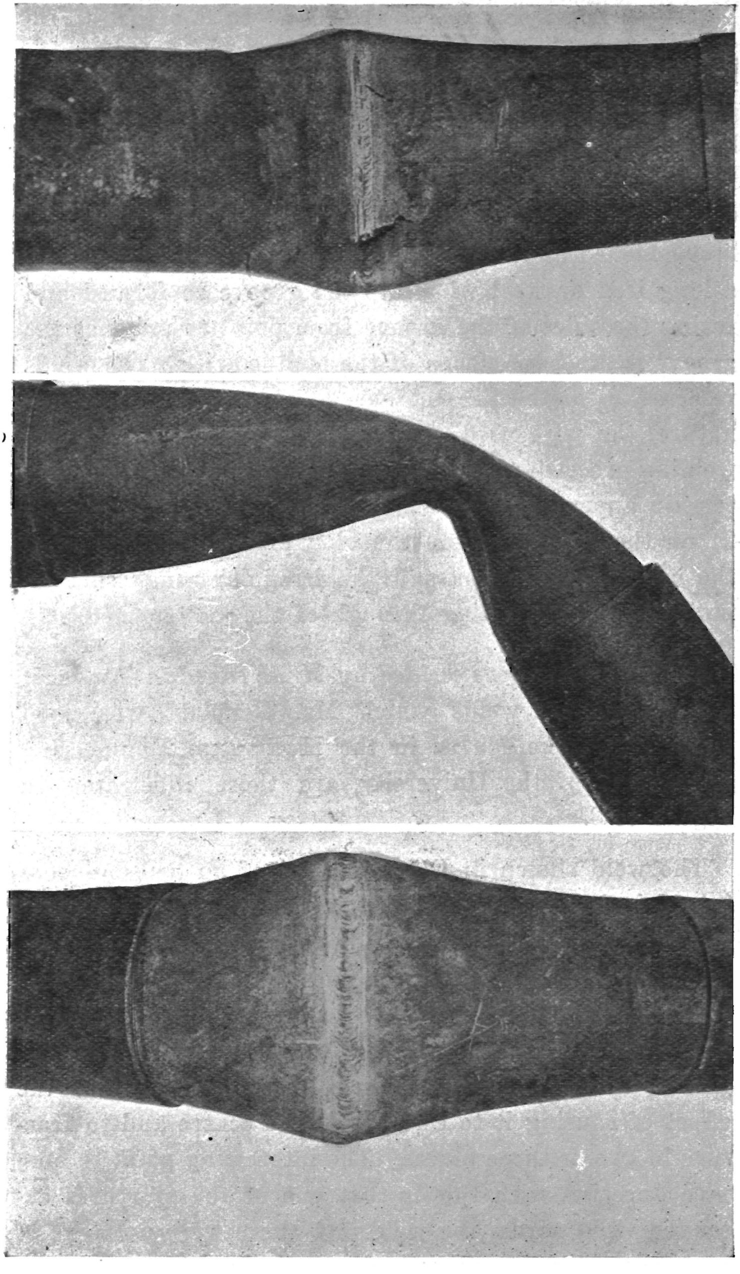

FIG. 1—Three Views of Welded Bore-tube after Welding.

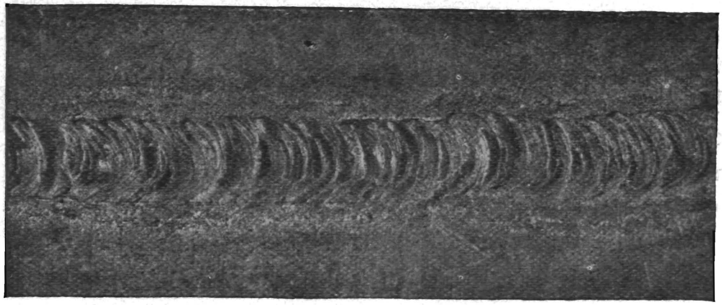

FIG. 2.—Top side of Weld showing Pooling.

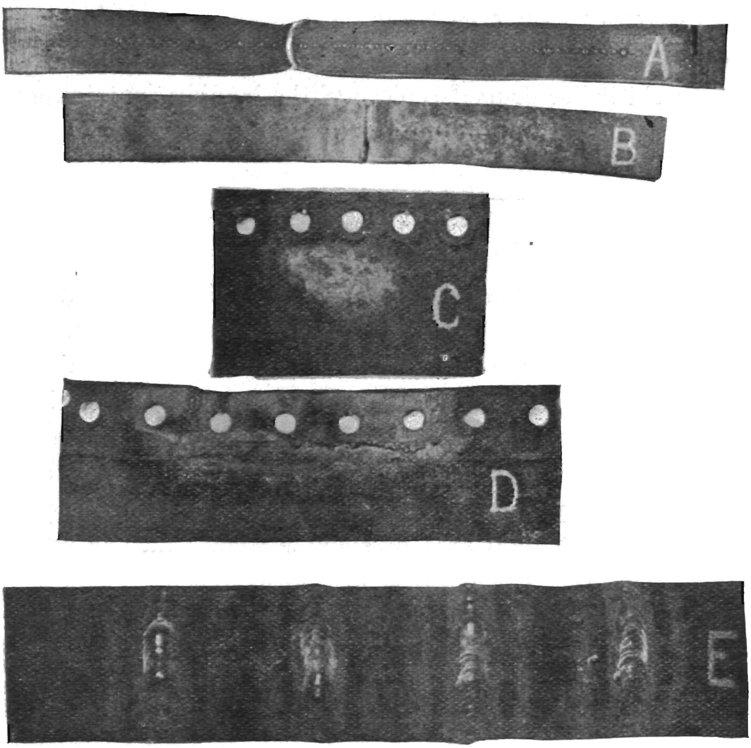


FIG 3.—A. Unwelded test piece. B. Welded test piece. C. Repair of wasting in boiler plate. D. Inside of boiler drum showing section cut out by chisel and replaced by welding. E. Short lengths of boiler tube welded together.*

* NOTE.—E is not to the same scale as A, B, C and D.

Another illustration of the process is shown in Fig. 3 E, which illustrates a boiler tube 2 inches in diameter and $\frac{1}{8}$ inch thick, from which a number of short lengths were cut. These were subsequently welded together again with a view to demonstrating that the welds could be made so uniformly that the pieces when joined up left the tube perfectly axial.

Other tests are shown in Fig 3 C and D. C was a piece of plate cut from a very old boiler and exhibiting a large depression caused by wasting and corrosion. Such holes can readily be filled up by the welding process, forming a very useful patch. The exhibit shown at D was part of an old boiler drum;* a piece of the landing containing four rivet holes was cut out and replaced by means of the acetylene blow-pipe.

4. *Efficiency of Weld.*—The most important question, however, is that of the efficiency of the joint produced by welding, and in order to get some idea of this the authors asked Mr. Kennedy to weld a joint with special care, in the middle of a test bar, so that the action of the welded bar, when placed under load in the testing machine, might be compared with that of an exactly similar unwelded bar. The two bars are illustrated in Fig. 3 A and B. They were approximately 2 inches wide and $\frac{1}{2}$ an inch thick, giving a total area of about a square inch in section. The results of the tests are illustrated by the autographic stress-strain diagram (Fig. 4). Both bars behaved in a practically identical manner up to the yield point, but from there to the point of fracture their properties are evidently widely different. The unwelded bar had a total elongation of 33.7 per cent., while the welded bar elongated only 5 per cent. There was a local

* D in Fig. 3 was subsequently cut out of the drum. The figure scarcely does justice to Mr. Kennedy's skill, as the drum used was so misshapen as to make it difficult to get a photograph which does not look distorted.

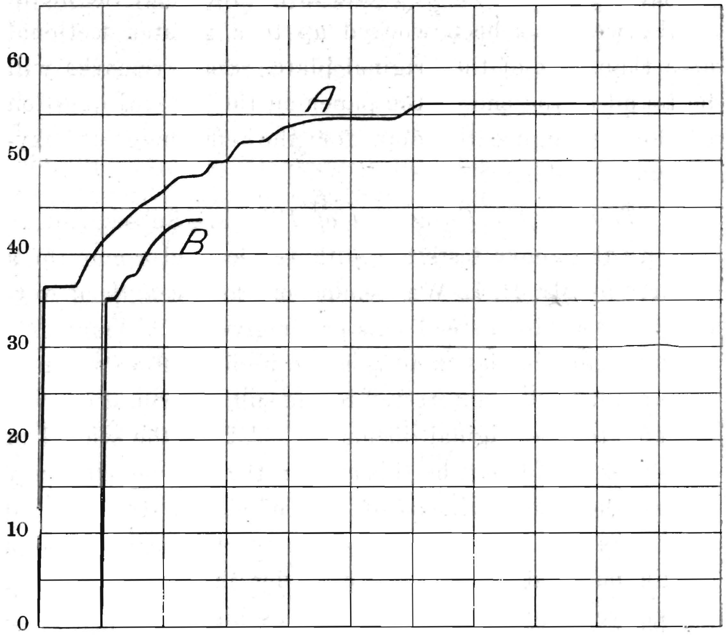


Fig. 4.—Stress-strain Diagram for Test Pieces A and B.
Scales:—Vertical in 1000 lbs. units; horizontal in ¼ inch units.

elongation of .80 inch on the unwelded bar, and of approximately .14 inch on the welded bar. The ultimate strength was 25.47 tons per sq. inch for the solid bar, and 19.58 for the welded bar, equivalent to an efficiency for the joint of 77 per cent. The fracture of the weld showed a somewhat crystalline structure, while the solid bar exhibited the characteristic clean break of mild steel. Such a figure as 77 per cent. efficiency is lower than what is often quoted as the strength of an oxy-acetylene weld. In fact, extravagant statements are often made that such welds are stronger than the original material of the plate. The authors' experience with this and other welded joints would lead them to conclude that such can rarely be the case, and even if tests are quoted to prove it, the explanation will usually be found in the fact that the metal at the weld has been worked up to a greater sectional area than that of the original plate. Some remarks will be found at the end of the paper on the general question of the safe figure to adopt for the efficiency of oxy-acetylene welds.

5. *Tests at the University of Illinois.*—Subsequent to making the above tests the authors received a copy of a report* by Mr. H. L. Whittemore on the strength of oxy-acetylene welds in steel. This paper gives an account of a most valuable series of tests made under different conditions; and anyone interested in the subject would do well to refer to the original document. Taking the second of the series carried out by this author, the average efficiency for all the test specimens of each of eleven strips varied from 64.4 per cent. as a minimum to 86.6 per cent. as a maximum; and the author concludes that as a result of his entire enquiry 85 per cent. is as high as may be expected when the weld is of the same thickness as the plate.

## SECTION B.

6. *The Method of Failure of Autogenously-welded Drums*—The observations contained in this section of the paper arose out of an investigation into the bursting of a welded drum, with which the authors were professionally connected some time ago. The drum, as appeared from the evidence given in the course of a public enquiry, was one of a large number, and was used for the conveyance of sulphuric acid. The drums are specially made for this purpose amongst others, and one rarely hears of any of them failing under ordinary service conditions. The customary method is to keep them nearly full of the strong acid and to open the bungs at short intervals in order to make sure that there is no accumulation of

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* The Strength of Oxy-acetylene Welds in Steel. University of Illinois, Bulletin No. 45, Sept., 1910.

pressure due to the formation of gas by the action of the acid on the metal. It did not clearly appear from the evidence given at the enquiry in this particular case how long a time had elapsed between the last opening of the bung and the actual failure of the drum. The point is not important for our present purposes, and it is sufficient to say that it was clearly proved that considerable pressure had accumulated in the drum at the time of bursting. It is, however, a matter of considerable technical interest and importance to determine the conditions of stress and strain set up in such drums, and the maximum pressure which they can bear without risk of failure. The authors had the opportunity of examining the action of a number of such drums when exposed to pressures extending up to the point of failure, and the present statement is a summary of the results obtained and the conclusions arrived at.

The general construction of the drum is exhibited in Figs. 5 and 6. The approximate dimensions are—internal diameter, 25 in.; length, 44in., thickness, 1-10th of an inch. It is provided with concave dished ends, and is encircled by two roller bands of the section shown. The material is Siemens-Martin plate, and the longitudinal joint, as well as the two circumferential joints at the ends, are, apparently, oxy-acetylene welded, as is also the bung connection. The drum that failed did so by opening along a portion of the longitudinal weld (see Fig. 5) while it was being transferred from the wharf to a lorry. Unfortunately the accident resulted in the death of one of the men engaged on the work, and there can be no doubt that close examination of these occurrences is amply justified in order to minimise the risk of such accidents.*

* The absence of any official organisation for conducting enquiries into mishaps and accidents of all sorts in this State continues to be a reflection upon our public life. It is extraordinary how many accidents, often involving serious risks of life, to public vehicles, trains, boilers, structures etc., occur, and no report of an investigation into their causes is ever made available to the public except in a few instances where lives have been lost and the circumstances surrounding the case appear to be such as to demand a technical enquiry being held for the assistance of the Coroner.

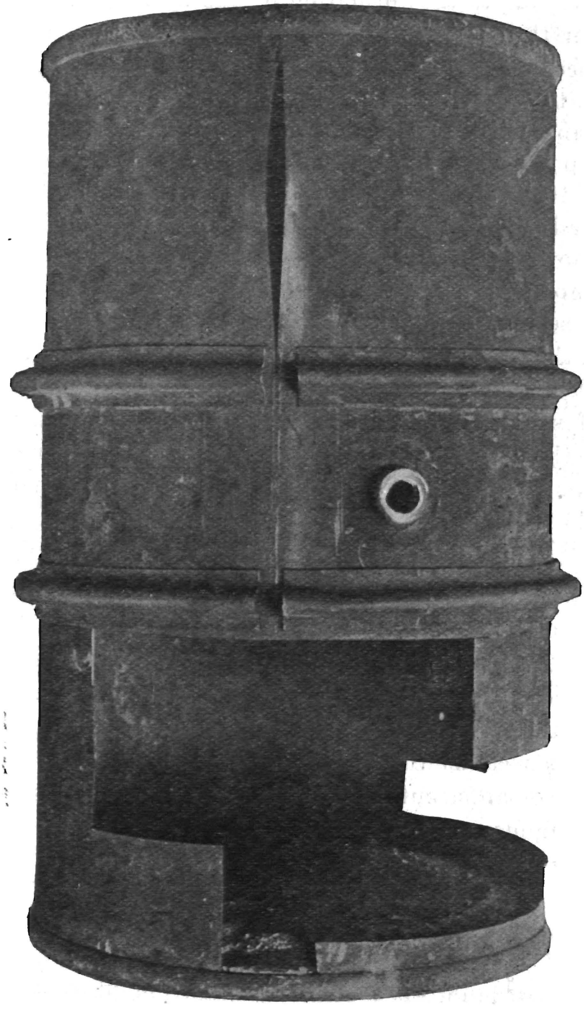

FIG. 5.—Photograph of drum A showing the failure of the longitudinal weld. The roller bands have been cut to expose the whole of the longitudinal joint.

7. *Quality of the Material in the Drums.*—Various test pieces were cut, both longitudinally and circumferentially, from the cylindrical portions of the drum which burst, and in addition test pieces were also taken

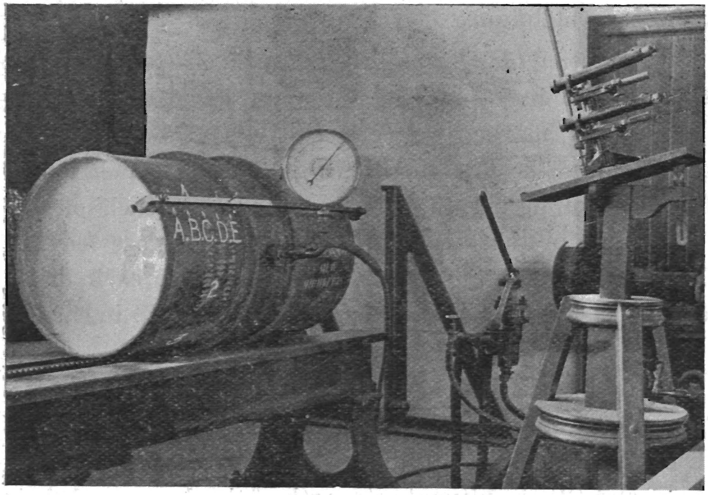


FIG. 6.—General Arrangement of Apparatus for Testing.

from two other drums of similar construction in order to determine the average value of the material in such drums in general. Owing to the relatively small dimensions of the thickness of the drum wall as compared with the width of the test piece, it was not easy to obtain very satisfactory test pieces. Several different shapes for test pieces were tried, some of standard dimensions and some a good deal wider in relation to the thickness of the material. The details of these tests are, however, unimportant, as the whole of them showed good breaking strengths (averaging 24 tons per sq. in.), and very good ductility, while the fractures all indicated a good quality of material, with no suspicion of any flaw or defect. Hence it was concluded that the material in the drums was probably uniformly good, and that the failure could not be attributed to faulty material. During the course of these tensile tests the modulus of elasticity was also determined by means of Martens' Mirror Extensometer, and was found to be approximately 29,000,000, which is about a normal figure.

8. *Tests on the Bursting Strengths of the Drums.*—The authors had an opportunity of examining six of these drums, marked respectively A, B, C, D, E, and F, and of these the first-mentioned is the one which burst. The firm supplying the drums states that each one is tested to a pressure of four atmospheres before leaving the works, so that it is safe to assume that each drum had at least a pressure of about 60 lbs. per sq. in. inside it at one stage of its existence.

The object which the authors had in view in making these tests was to determine (1) the way in which the drums were strained, as the pressure was applied inside them, and (2) the ultimate strength of the drums and their mode of failure. With the dimensions quoted above, and assuming the drum to act as a thin cylinder, and neglecting complications introduced by the dished ends, the bursting pressure would be approximately 450 lbs. per sq. in. Looked at in this way, and allowing even a large factor of safety, it is obvious that the strength of the drum would be more than sufficient for the work required of it. Assuming an efficiency for the weld of even as low as 50 per cent., the minimum bursting pressure would be about 225 lbs. per sq. in., and taking a factor of safety of, say, 5, the safe working pressure would be about 45 lbs. This would be the ordinary way of getting a rough idea of the working strength of the drum, and a proof pressure of 60 lbs. would be a satisfactory one to apply. The actual stresses, as indicated by determining the strains, were found to differ widely from these figures, and were curiously complicated, partly owing to the effect of the dished ends, which tend to bulge out as the pressure comes on them, and in doing so to thrust the cylindrical portion of the drum laterally, and partly also to the effect of the welded rings and the roller bands; also the effect of any irregularity of shape of the drum or slight denting on the surface was very marked. This combination of actions was found to bring about the unexpected result in some of the drums, that portions of the cylindrical drum surface near the ends, which ordinarily would be regarded as carrying a tensile stress because of the pressure of the liquid inside the drum, were actually not in tension at all, but were very markedly in compression. The fact is worthy of note as showing that no ordinary method of computing the strength of such a drum is of much value.

The method followed was to attach a modification of the Martens' Mirror Extensometer to the surface of the drum at different points and measure the extension or compression of the short length of the material carrying the extensometer. Within the elastic limit of the material these extensions and compressions are measures (when appropriate scales are used) of the stresses in the material. Fuller detail of the method used will be found in Section C. Amongst the observations taken on Drum F were those across the longitudinal weld itself, and it was found that the weld was subject to a compressive, and not to a tensile strain as would ordinarily be imagined. The pressure was applied inside the drum by means of a boiler-test pump operated by hand, the pressure being measured by a large pressure gauge carefully standardised for the purpose (see Fig. 6). The pressures as used inside the drum, when obtaining the relative strains of the material in different parts, were not allowed to exceed 40 lbs. per sq. in. so as to avoid any risk of permanently straining it.

After making this preliminary examination of the strains on the surface of Drum F the pressures were gradually increased up to the point of failure. When the pressure had reached 85 lbs. per sq. in. one end of the drum began to bulge, and as the water was kept on being forced into the drum that end pushed out until it had changed from the concave to the completely convex shape. The drum still held the pressure, however, and the water was pumped in until the gauge read 90 lbs., when the other end began to bulge, and here also the bulging went on until the other end was convex instead of concave. There was still no sign of a leak, and the pressure rose gradually inside the drum till it reached 105 lbs. per sq. in., when a slight leak began to show on the welded ring at the end of the drum. At this stage an attempt was made to see how the longitudinal weld would stand shock when subject at the same time to heavy pressure.

With both ends bulged to a complete convex shape and a pressure of approximately 100 lbs. inside the drum the longitudinal weld was violently hammered near one end of the drum with an ordinary engineer's hammer. It was only after some twelve or fifteen blows that a very slight weep hole opened in the weld and allowed a fine stream of water to escape. On now operating the hand pump the pressure inside the drum rose 5 or 6 lbs. (that is up to about 105 lbs. per sq. in. again) when the weep hole closed up. This operation was repeated several times, and always with the same result; even when several weep holes were started in the longitudinal weld by hammering, they always closed up when the pressure was increased by a few pounds. This action is probably due to the compression existing in the material of this particular drum, as already described, and which would naturally increase as the pressure rose, and would tend to close up the small weep holes. The experiment seems also worthy of note as showing the general "toughness" of such drums when subject to fairly hard usage. Experiment on other drums did not show a compressive strain on the surface, as was the case in Drum F above, except at one or two places where a small compressive strain was indicated. The fact seems to be that the stresses and strains set up in such drums will vary in a very irregular manner, and will depend upon accidental details as to shape and stiffness of the different parts brought about during the process of manufacture. This is particularly so in the neighbourhood of the ends. Further experiments made on Drums B, C, D and E confirm the numerical results above stated as far as the ultimate strength of the drums is concerned, and so need not be referred to further.

9. *Strength of the Longitudinal Weld.*—During the course of the public enquiry into the cause of failure of the longitudinal joint in Drum A, some evidence was given tending to show that such a joint has very little strength, and is not to be depended on at all. The argument was based upon the experiment of cutting a strip 2 inches wide out of Drum A in a circumferential direction, having the weld across its middle. It was stated that such a strip could be readily broken by bending in one's hands. It is obvious that such a test is not a fair one under any circumstances, as the welded joint in the drum is not intended to carry a transverse load, and further, it was not clear that the welded joint had not been rather severely handled in cutting the strip out of the drum. At any rate, the authors repeated the test by very carefully sawing and drilling a similar strip (viz., 2 inches wide and about 20 inches long) from Drum A, having the 2 inches length of the longitudinal weld across its centre. This piece was then brought to a red heat in the gas furnace and carefully straightened. On being put into the testing machine the piece broke at the weld