Discussion.

The PRESIDENT, in moving the vote of thanks to the Author, referred to one of the earlier applications of electric welding which had brought about a change of method in this country. About 15 years ago he had been faced with the problem of producing the large turbine-drums of the S.S. "Carmania," and had solved it by the use of electric welding, which was in those days a little-known art. It had not proved very difficult to obtain a perfectly sound weld; the difficulty had been rather to ensure perfect physical solidity on each side of the weld. The physical strength of the welded portion could therefore not be regarded as being the true physical strength of the whole drum. Another difficulty, which had been surmounted, though not very easily, had arisen during the cutting of the grooves for fitting in the blading—there were over 10,000 blades on one drum. Also, caulking of the blading at each side of the weld had been a matter of some considerable difficulty. He mentioned that as an interesting point of history in connection with electric welding, because it was that difficulty which had caused hollow rolling to be introduced, and during the war every drum for turbine work had been hollow-rolled instead of welded. These remarks referred to the welding of thick articles, the drums in question being $1\frac{3}{4}$ inch thick. He was quite aware that the welding of thin articles, such as the Author dealt with, was a very different problem. He could not help feeling that electric welding suffered from a little prejudice, because it had been primarily introduced for the purpose of repair, and it was not always used judiciously in that connection. Taking, for instance, the case of steel castings which were not quite satisfactory, there was no possible objection to applying electric welding for the purpose of repair if it was done under very strict supervision; but unless the whole of the defect —whether unsoundness or the effect of contraction—was absolutely removed before welding, the welding covered up unsatisfactory work. There was no doubt whatever that among engineers electric welding was not regarded with very great favour. That had probably stood to some extent in the way of the introduction of electric welding for new work. The Author dealt with very light structures, and it appeared that he was not relying on the ultimate tensile strength of the weld being equivalent to the original tensile strength The President.

The President. of the steel, but regarded it as being at least equal to the strength of a riveted joint. The President could not help thinking that the element of stiffness which a riveted gasholder possessed must in itself be of some slight advantage, especially for avoiding buckling in erection, as well as to some extent for permanent strength. The Author had certainly put before the members a wider application of electric welding than they had had in their minds previously, and for that reason he had done service to The Institution. He had shown that it might safely be applied to new structures on a very large scale, and he had given them information which could not fail to help them in their work in that direction. The President saw at once one direction in which electric welding might be applied. The roofs of blast-furnace gas-heating stoves were very troublesome from a repair point of view, being very light structures; and the removal of the whole of the roof and rebending and fitting it was a long and costly matter. If it were possible to adopt electric welding in that connection, he thought blast-furnace managers and engineers would welcome it.

Mr. Botley. Mr. C. E. Botley considered that all gas-engineers would peruse the Paper with great interest, and with advantage. Electric welding was commonly employed in gasworks, though possibly it was more used in connection with repair work, such as the repair of cast iron, and temporary repairs of boilers, especially in an emergency. It was also used for special high-pressure steel mains, which were coming very much to the fore in connection with high-pressure gas-distribution. He thought the Author rightly said that nothing had been done in this country on such an extensive scale as in Australia. The repair of a gasholder in the ordinary way by means of electric welding was an extremely dangerous operation. The Author, with the thoroughness which characterized engineers in the Dominions, where necessity was very often the mother of invention, had foreseen the difficulties, and his application of electric welding to the renewal of the crown of a holder was both ingenious and convincing. The electric welding of thin sheets, unless the operator was very experienced, more often resulted in a hole than in a weld. The method which the Author had adopted in repairing the crown of the holder was the introduction, while the gas was in the holder, of a metal net over the crown, so arranged that there was something underneath the joint which would be impervious to the penetration of the flame. The Author had been very successful in training a number of welders, which was one of the most important matters. It was astonishing how expert the men eventually became; but they required sound training. The Author made out a case for electric welding on the point of cost, but Mr. Botley's experience was that the electrodes were expensive; and he would hesitate to depart from established practice without some convincing proof that economy would result. In the absence of further proof, he would rather hesitate to accept the Author's explanation of the cause of the failure of one of the South Melbourne holders. The Author attributed the defect to temperature-stresses, but, having seen the lantern-slide exhibited, Mr. Botley was of the opinion that it was more probably due to internal corrosion. From the programme of repairs which the Author set out, it would appear that the conditions in Melbourne were quite exceptional, with regard to either the original construction of the gasholders or their deterioration. Certainly a very serious problem of reconstruction had had to be faced. The description in the Paper of the ingenious method of coupling the middle and inner lifts together had puzzled him a great deal, and even after having seen the slides he was not quite clear as to how it had been done. But the point was that the Author had brought electric welding to such a successful pitch that he had been able to put into service a badly damaged holder in a minimum of time and doubtless at a minimum of expense. Mr. Botley.

Mr. T. M. Aitken remarked that for many years he had taken an interest in welding in this country, but he was afraid that no welded structures had been undertaken comparable in size with the Author's work in Australia. However, in spite of that fact, a few interesting applications had been made in this country. About 6 years ago the firm with which he was connected, the Anglo-Swedish Electric Welding Company, had been entrusted, after very careful tests in the first place, with the welding of most of the joints of a large marine boiler, designed and constructed by Messrs. R. & W. Hawthorn, Leslie & Company. The diameter was 15 feet 6 inches, and the boiler was of the usual marine type with three internal furnaces. It was constructed for 180 lbs. per square inch working-pressure, the shell plates being $1\frac{1}{4}$ inch, and the end plates $1\frac{5}{16}$ inch thick. The end plates, instead of being flanged and riveted to the shell, were simply plain disks put into a small groove planed in the shell plates before they were put through the rolls. After erection, a line of fillet welding had been run from the outside and the inside. That was the only joint between the end plates and the shell. The joints in the combustion-chambers were all welded. There was no double thickness and there were no rivet-heads, which, of course, was a great advantage. No leak had been observed even on the first testing of the boiler at 360 lbs. per square inch. That boiler had now been working for 6 years under trying conditions with oil Mr. Aitken.

Mr. Aitken. fuel and forced draught, and it had never shown the slightest weakness. A design of that description offered very great advantages. To flange, level, and anneal plates 16 feet in diameter and $1\frac{5}{16}$ inch thick was a difficult and expensive operation, and he believed that about 20 tons of fuel were required for the work on a boiler of that size. The drilling for this joint required 290 holes at each end, making 580 holes in all, $1\frac{5}{16}$ inch diameter, through a double thickness of plate of more than $2\frac{1}{2}$ inches. Thus there was considerable saving in the welding process. Referring to the Author's comparison between riveted and welded joints, Mr. Aitken cited some tests carried out a few years ago on plates $1\frac{1}{4}$ inch thick. A treble-riveted butt-strap joint used in a certain structure had been very severely stressed, and his firm had been asked whether there was likely to be an improvement if the joint were welded in addition to being riveted. When they expressed themselves as quite confident about the superiority of the welded joint, they were invited to prove it. Test-pieces were made of 24–28-ton steel exactly similar to the part of the structure in question, some being riveted only, and others riveted and welded; they were sent to Professor B. P. Haigh, M. Inst. C.E., of the Royal Naval College, Greenwich, for testing. Professor Haigh designed a special extensometer to check not only the extension of the pieces but also the lateral deflection, the main object being to find what load the joint would take without showing any permanent set. Professor Haigh therefore subjected the pieces to small increments of load of about 2 tons each, each additional load being taken off and measurements taken to see how the joint as a whole had been affected in its elastic properties. The results showed that the riveted specimen took a permanent set at a total load of $12\frac{1}{2}$ tons (corresponding to 2·8 tons per square inch net area of plate), whereas a specimen of the same dimensions which had been welded in addition to being riveted took 60 tons load (corresponding to about 13·3 tons per square inch net area of plate) without any permanent set whatever, and any load beyond 60 tons would have been in the neighbourhood of the elastic limit of the plate itself. Upon those tests Professor Haigh reported that the welded joint was certainly about four times as strong as the riveted joint. Results of that kind indicated that there appeared to be no question that in due course the riveted joint would be replaced altogether by the welded joint.

Mr. Plumstead. Mr. A. E. Plumstead observed that the Author stated that electric welding was in its infancy, especially for constructional work. That no doubt was quite true, for the English manufacturer was rather slow to adopt new methods of construction. It might perhaps be due partly to the fact that he had been more or less Mr. Plumstead "sold" on more than one occasion by an incompetent welder, because in the early days of welding much inferior work had been done, and the progress of the welding trade had been retarded thereby. Another reason might be, as a previous speaker had pointed out, the high cost of the best brands of electrodes. The Paper was of real value to welding engineers, who, he thought, should be more persistent in bringing to the knowledge of general engineers the great possibilities of welding. In that respect they should make a strong point of impressing upon engineering manufacturers the desirability of closer co-operation between the designer and the welder. Designers were rather too apt to design their work without due regard to the welding. By closer co-operation with the welder they would be able to obtain greater simplicity in design and more economical results. The Author did not give the relative costs of a riveted gasholder and a welded gasholder. Cost was of primary importance to engineers, and he thought that the Author could make out a case for cheaper construction by electric welding, with an important saving in time also. With regard to the collapsed crown of the gasholder at South Melbourne, he asked what the Author considered to be the cause of the internal corrosion—whether it was really a result of the stress caused by the movement of the plates due to varying temperatures, to the difference in the thickness of the crown-plate and the curb-plate, or even perhaps to inequalities in the manufacture of the plates, or whether it was due to chemical action from the moisture in the gasholder. He would also like to know the Author's view as to the cause of the gas igniting after the crown had collapsed. Further, he would appreciate information as to whether pure-iron or mild-steel plates were better for gasholder construction by welding. A little more detail regarding the welding itself would have been acceptable, as well as some explanation as to how allowance was made for contraction effects in the weld. Some of the plates were probably 6 to 8 feet by 4 feet, so that considerable contraction would take place in the weld after proceeding, say, half-way towards the end of the plate. He had in mind the probability of the invention of a portable seam-welder. If such a thing could be devised, it would appear to him to afford a solution of the problem of welding $\frac{1}{8}$-inch steel plates, especially in the construction work of a gasholder. The Author described (p. 169) the reconstruction of a gasholder in which new sheeting was superimposed over the old crown and the whole material welded together, the gasholder remaining in service the whole time. That was, as the Author claimed, a bold experiment, but Mr. Plumstead, if he might say so, had carried out a bolder experiment

Mr. Plumstead. in making repairs to a large gasholder where there was more danger in doing the work. Mr. Thomas Glover, M. Inst. C.E., had been in difficulty with regard to a gasholder of 800,000 cubic feet capacity at Norwich, the plates of which had suffered from serious external corrosion. Curiously enough, the corrosion had only affected some of the plates; that was to say, there was one bad plate, or a group of two or three bad plates, between plates which were in perfect condition. The gasholder was 33 years old; and he was unable to say whether the plates were of iron or steel. The method of repairing that gasholder differed from that described in the Paper. The Author had put a steel network over the gasholder and welded the plates together separately from the crown of the gasholder, making the joint between the new and old crowns on the curb-plate, which was perhaps $\frac{3}{8}$ inch thick. In the case of the Norwich gasholder, however, the repair had been carried out by welding $\frac{1}{8}$-inch steel plates with a lap weld over the actual defective original $\frac{1}{8}$-inch plates. About 120 new plates had been put on the crown and sides of the gasholder while it was actually in use. During the repair, leakages had had to be contended with. Bolts and fish-plates had had to be removed from the top of the gasholder, leaving holes up to $\frac{3}{4}$ inch in diameter; and steel washers had been pressed on over the holes and welded round before putting the new sheet on over the old one. The repairs had been effected in about 3 months, and had proved perfectly satisfactory in every way. Probably the Author would not in future, when he had damaged side sheets in a gasholder, weld the upper and lower lifts together and thereby reduce the storage-capacity of the gasholder, but would weld new plates on the outside and thus maintain the whole of the storage-capacity. He must confess he could not quite see the advantage of the radial-bar system of strengthening the crown (p. 176), because the radial bars apparently were only fixed on the curb-plate and at the centre. It appeared to him that they should have been lap-welded, or fixed in some way to the crown of the gasholder. Even if any strength were obtained by that method, he imagined there must be disadvantages, inasmuch as a great deal of corrosion would be set up between the radial bars and the crown-plates, and there would be cavities for the accumulation of dirt and moisture, which would be detrimental to the roof of the gasholder: and there would probably also be some friction, due to expansion and contraction, between the radial bars and the crown plate. The President had expressed some doubt as to the strength of thin plates—say $\frac{1}{8}$ inch thick—on each side of a welded joint. During the repair of the gasholder to which Mr. Plumstead had referred, samples of the welds had been taken haphazard and sent to a laboratory for testing. The report on the results of those tests had been to the effect that the strength of a single-lap-weld joint, taken at random from the various pieces of welded material lying about, was 97·9 per cent. of the strength of the original plate—more than 20 tons per square inch. It was therefore quite evident that a good strength could be obtained by electric welding. Mr. Plumstead

Professor W. E. DALBY remarked that the Paper showed it was quite possible that engineers might look to wide applications and wide extensions of the process of welding. He could recall some special classes of welding on machine parts and so on, but this was the first time he had had definite information as to welding on such an elaborate scale. There were, however, questions which would have to be settled before constructional engineers could be convinced of the desirability of the general application of the method of electric welding, and that was, the effect of electric welding upon the elastic properties of steel or iron. He remembered an electric welding machine being introduced a good many years ago into Crewe works, when there was a proposal to weld lap joints of boilers, etc.; but it was found that a lap-welded plate, although quite as strong as the original plate, had lost its peculiar elastic property, and 30-ton steel was somewhat hard and brittle around the region of the weld. Whether that difficulty had been overcome or not he did not know, but that was a point about which engineers would have to be convinced. The Paper contained references to, and examples of, numerous tests which had been carried out on electrically-welded joints, but a statement of the ultimate strength of a welded joint, as given on p. 164, was not enough to satisfy engineers that it was safe to use it in general constructional work. Ductility might be lost, the metal might be hardened, and its property of standing alternating loads might be destroyed. Those were points which would have to be answered before electric welding made rapid strides among engineers. Mr. Aitken had referred to a boiler which had been constructed by electric welding. Professor Dalby would like to know a little more about the processes of annealing applied to the plates after welding. In his experience of electric welding at Crewe it had not been possible to get, after electric welding, uniformity of the material across the weld. Gasholder construction was an exceptional application of electric welding, because the hardening of the metal did not matter quite so much in that case. Professor Dalby.

Mr. AITKEN stated that no annealing whatever had been done in connection with the boiler to which he had referred. Mr. Aitken.