MEETING IN LONDON 19th MARCH 1952

The Forty-First Annual General Meeting of the Institution was held at the Institution of Mechanical Engineers, Storey's Gate, London, on Wednesday 19th March 1952, at 5.30 p.m., Mr. J. S. Tritton, President, occupying the Chair.

The Minutes of the previous Meeting held on 20th February 1952, were read by the Secretary, and were confirmed and signed as correct.

After the business of the Annual General Meeting had been concluded (*for report see Journal No. 225—Editor*) the President introduced Mr. J. F. Harrison, M.I.Mech.E. (Member of Council) who presented his paper entitled " The Application of Welding to Locomotive Boiler Copper Fireboxes," which was afterwards discussed and for which, on the motion of the President, a vote of thanks was accorded to him.

THE APPLICATION OF WELDING TO LOCOMOTIVE BOILER COPPER FIREBOXES†

*J. F. HARRISON, M.I.Mech.E. (Member of Council)**

Paper read before the Institution in London on 19th March 1952
Repeated in:—
Darlington 26th March 1952 (page 205)
Doncaster 27th March 1952 (page 208)
Derby 2nd April 1952 (page 210)
Glasgow 9th April 1952 (page 214)
For Author's combined reply to discussion see page 216

PAPER No. 511

SYNOPSIS

The Paper covers the complete range of development work necessary in the application of copper welding to locomotive boiler fireboxes from the initial experimental work in the production of test pieces through the various stages of repair work to the final manufacture of an all-welded copper firebox having copper stays seal welded. Reference is made to alternative methods of application for various forms of repair in use throughout this country and ends with suggested possible lines of future development.

INTRODUCTION

It must be made clear that this Paper is not a general dissertation on the art of welding copper, but deals primarily with the application of this well established process to the repair of locomotive boiler fireboxes.

† Author awarded the Institution of Locomotive Engineers Award (value £15) for this Paper.

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HISTORICAL

The repair and construction of locomotive copper fireboxes by welding is, of course, not a recent development, since simple repair work of this kind was being carried out in Germany in 1916, and by the early 1920's more elaborate work, such as the insertion of patches, the repair of tubeplates, and the insertion of half or three-quarter sides, had been successfully accomplished. By 1925 several all-welded copper fireboxes had also been built. In this country, however, it was not until 1927 that the repair and manufacture of new copper fireboxes by the oxy-acetylene welding process had become an established practice, the Great Western Railway being the first in the field followed some time later by the London Midland and Scottish Railway.

On the London and North Eastern Railway, Great Central Section, the cost of firebox repairs was exceptionally heavy, frequent copper stay and plate renewals being necessary owing to the very bad water conditions met with in that region, possibly the most damaging to boilers in this country. During the war years great difficulty had been experienced in obtaining the necessary copper plates for renewals, so the Author, then Mechanical Engineer, Gorton, originated at those works serious investigation into the possibilities of effecting repairs to copper fireboxes by the oxy-acetylene welding process. In 1943 a Technical Assistant, who was a specialist in welding, was engaged to carry out the necessary development work under the jurisdiction of the Author.

The first objective was to ensure that any welds produced would have a tensile strength equal to that of the parent plate and successfully bend through 180 degrees when hot. To reach this standard approximately six months of experimental work was found necessary.

Following this stage certain welding repairs were carried out on fireboxes, such as building up wasted radii in tube and doorplate flanges, and in December 1944 a further experiment was carried out by fitting to a Diagram 15 boiler (0.4 class 2-8-0 Freight Locomotive) two new lower half wrapper sides by welding. It is of interest to note in passing that this firebox gave a further $4\frac{1}{2}$ years of life, which equals approximately 60 per cent. increased life on an average firebox. From 1945 onwards a considerable number of half or three-quarter copper sides were fitted and repaired by welding. These experiments were further extended by the insertion of new plate in and around firehole mouth pieces, the insertion of pieces in tube and doorplate flanges (this latter development being considered from experience a better repair than the building up of worn plate edge laps), patches let into the wrapper sides (lower half) were developed where it was considered to be more economical than the fitting of a complete new half plate, the reinforcing of the radius of firehole flanges of the solid ring type doorplate, the welding of fractures in the tubeplate crowns from both sides simultaneously, and most recently the development of sealing the copper stays in the lower portion of the firebox wrappers.

The Author will deal with the various types of repair carried out at the Gorton Locomotive Works and describe in detail the difficulties and failures encountered, together with some of the remedies which were used to overcome them. Saving from this type of repair will be indicated and the question of training, supervision and testing of welding operators outlined, all, as the result of these experiments, carried out up to the present time.

It is not intended to describe in detail the experimental work, as this has been the subject of many papers in various Institutions, but before any actual repairs were carried out to fireboxes in boilers to be put into service a standard of welding was reached whereby the tensile strength of the welded portion of any firebox was equal to, or higher than, the parent body. It was found that this result could be achieved by welding with the intermittent method, i.e. the welding of a run of about 6 in. after which hammering is carried out and then further incremental lengths of 6 in. of welding and hammering coupled with the use of a copper filler rod with a silver phosphorus content (99 per cent. copper, .5 to 1 per cent. silver and .05 per cent. phosphorus). Fig. 1 indicates sample figures.

Filler Rod	*Ultimate tensile strength ton/sq. in.*	*Elongation %*	*Condition*
Electrolytic Copper	9.7	14	Single horiz. weld hot hammered
Copper Silver Alloy	14/17	22/25	"
De-oxidised Copper Plate	14	50/60	

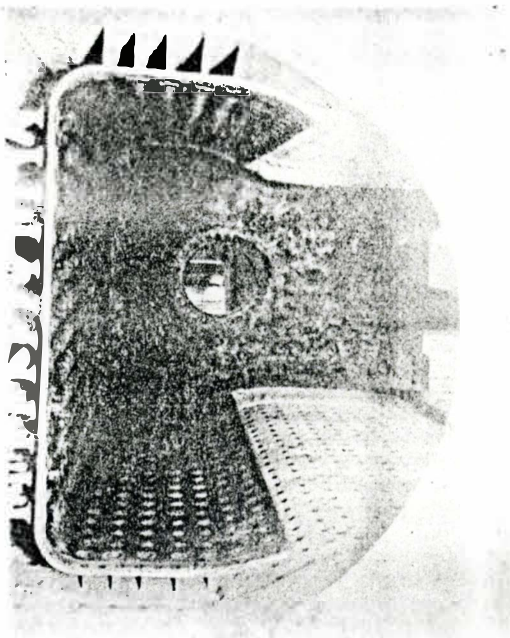
FIG. 1
PROPERTIES OF WELDS MADE WITH ELECTROLYTIC AND ALLOY FILLER RODS

It should be mentioned that for many years arsenical copper used for firebox plates was the " tough pitch " variety, i.e. it contained up to 0.1 per cent. of oxygen. It is well known that if welding of " tough pitch " copper is adopted with an oxy-acetylene flame containing an excess of acetylene, serious distortion and inter-crystalline cracking of the copper may result.

The reference to repair work in this Paper is concerned solely with de-oxidised copper plate to B.S.1174.

SOME ASPECTS OF THE USE OF COPPER WELDING

Prior to copper welding, defects which occur during the life of a firebox can be divided into two main groups, (1) those which can be repaired by patching or bushing with the firebox in position, and (2) those which necessitate the complete replacement of one or more of the flanged plates of the firebox. So far as the first group is concerned the most frequent troubles are wasted flange plate laps, wasting of the plates around the firehole and local grooving of the plates around adjacent stay holes. It is obvious that a saving can be made by the use of copper welding on this class of repair, and in fact apart from



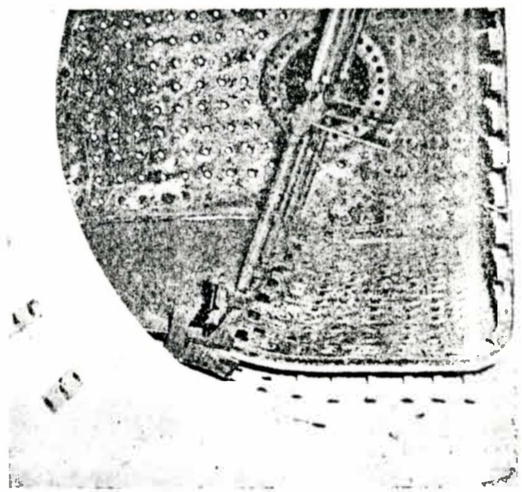


FIG. 2 (*top*) FIG. 3 (*bottom*)
INSERTION OF NEW HALF OR THREE-QUARTER SIDES

any financial saving the copper welded repair reduces the possibility of leakage, as would have been the case had the firebox been repaired by the older form of repair, viz. patching and riveting. When the second group is considered, obviously a very much greater saving is possible by the use of welding, as it becomes unnecessary to remove the faulty plate, it being quite possible to make a suitable repair with the plates still in position in the boiler.

It is now proposed to show how the various types and methods of repair are carried out.

INSERTION OF NEW HALF OR THREE-QUARTER SIDES

The defective wrapper side is cut away (Fig. 2); the edge remaining is chipped and bevelled (a single bevel at an angle of 30°), the new plate having been machined and bevelled at an angle of 30°, so that a resultant included angle of 60° is obtained, is then fitted into the firebox, secured in position by means of a steel backing strip, separated from the steel wrapper and the inner opposite copper plate by screw jacks and tubes (Fig. 3). This new plate is set to a pre-determined gap to allow for contraction, this gap being in the order of $\frac{3}{16}$ in. per ft. run weld. The weld is carried out intermittently, followed by light hammering with a pneumatic tool, i.e. after 6 in. of welding has been completed light hammering takes place whilst the weld metal is at a high temperature, i.e. plastic. This sequence of operations proceeds until the seam is completed, following which the surplus weld metal is chipped off; the usual sequence of operations then takes place regarding marking off, drilling, tapping, staying, etc.

Another method is to have two welders, one sitting astride the seam, the other parallel with the seam, on small trolleys, the welding of the joint being carried out continuously, the whole operation being performed in a short space of time, some 4 ft. 8½ in. in 28 minutes. In this case a copper backing strip is located at the back of the joint and becomes an integral part of the weld. This two-operator method necessitates the removal of the tubeplate in order that the men can back into the boiler barrel during the finishing operation on the welded seam. A flux is necessary with this method.

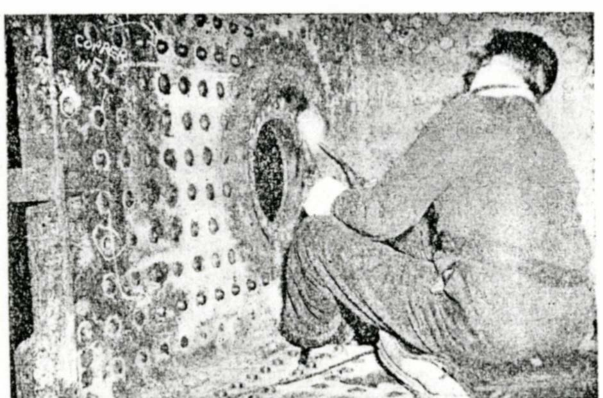


FIG. 4

OPERATOR REINFORCING RADIUS OF FIREHOLE FLANGE

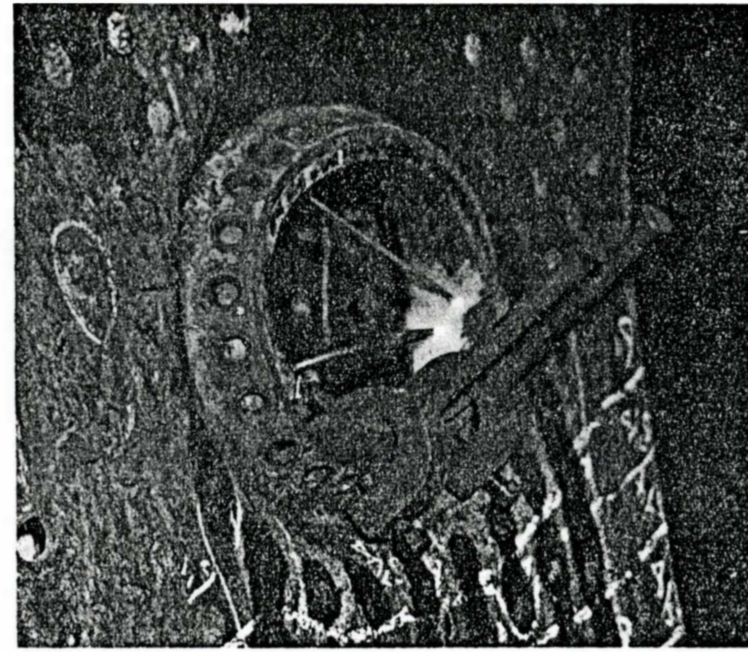


FIG. 5

WELDING OF NEW MATERIAL INTO DISHED FIREHOLE

FIREHOLE MOUTH PIECE, SOLID RING AND DISHED TYPE

Figure 4 shows an operator reinforcing the radius of a firehole flange. During the initial experiments to perfect this operation it was found that the heat applied caused such movement of the plate that the resultant contraction induced cracking, to overcome which it was found necessary to remove a number of the firehole rivets. The removal of these rivets enables the copper plate to expand freely during welding, and after welding has been completed the plate shrinks back so that the rivet holes are coincident with the steel firehole ring holes. Fig. 4 shows a right-handed operator. There are many cases, however, where left-handed operators are necessary.

Figure 5 shows a dished firehole having a new piece of material welded into position.

PATCHING

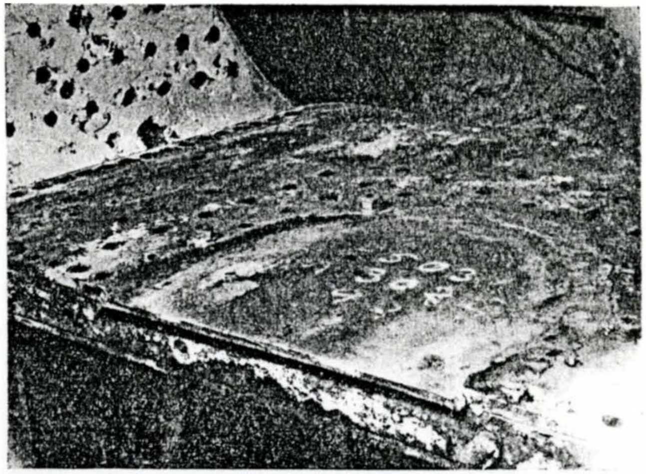
Figures 6 and 7 show a typical patch let into a lower half wrapper side. It will be seen that the area of the new plate, although small, is sufficient to enable this firebox to be put back into service.

MAKING GOOD WASTED FLANGES

Figure 8 shows a wasted flange plate lap which has been built up by welding; this latter process has now been displaced because it is considered a much more satisfactory job to weld in a new piece of plate, as already referred to, [illegible]ess the wastage is localised to 2 or 3 in.

TUBE PLATE CROWN FLANGE CRACKS

Normally the cracking or " reeding " occurs on the inside of the radius and extends to a depth of up to half the thickness of the plate.



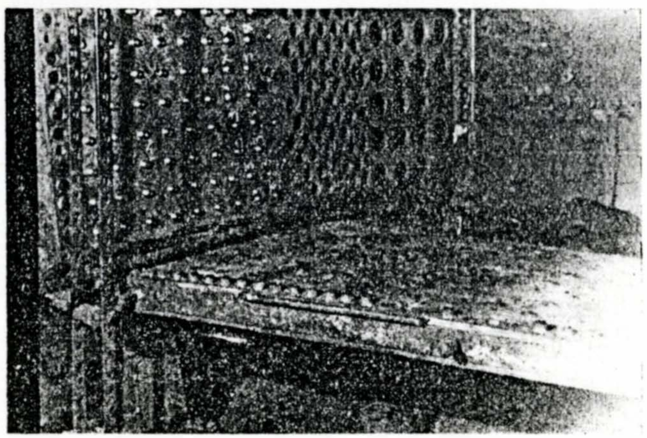


FIG. 6 (*top*) FIG. 7 (*bottom*)
PATCH LET INTO LOWER HALF WRAPPER SIDE

The cracks are cut out with a pneumatic chisel and welded in the normal way.

Occasionally, however, cracking occurs both on the inside and outside of the radius (within the water space).

Figure 9 shows a tubeplate severely cracked on the water side and shielded at the same time by the flange. This particular type of repair necessitated welding from both sides simultaneously, having the firebox on its side and the weld made vertically.

TUBEPLATE BRIDGES

A troublesome problem in the repair of fireboxes by welding has always been the tubeplate, where cracks occur in the bridges between adjacent tubeholes. It was found that a repair could be successfully performed, but the preparation and time spent to undertake it proved it to be uneconomical compared with the mechanical repair by bushing; bearing in mind that this applies only to tubeplates, the

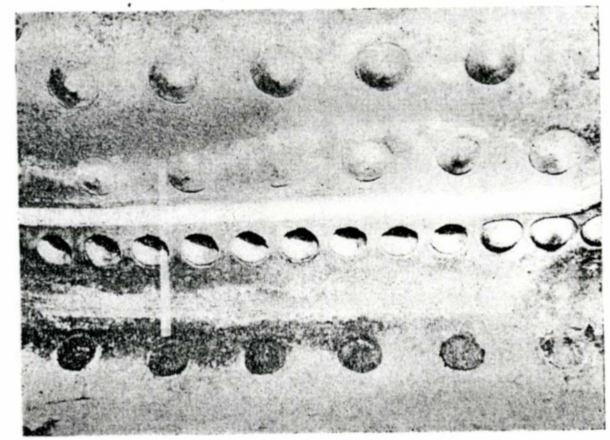


FIG. 8
WASTED FLANGE PLATE LAP BUILT UP BY WELDING

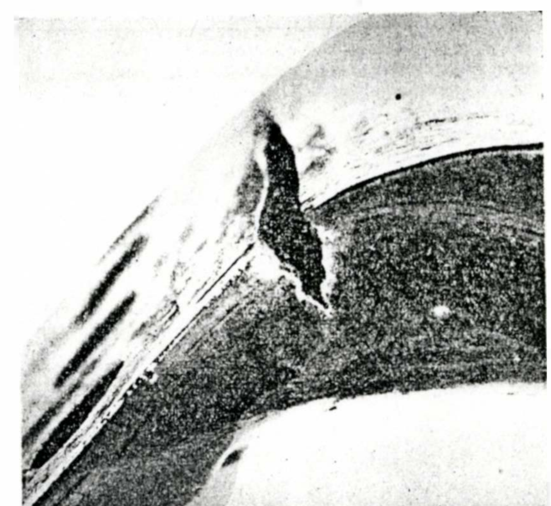


FIG. 9
CRACK ON WATER SIDE OF TUBEPLATE WHICH NECESSITATED WELDING FROM BOTH SIDES SIMULTANEOUSLY

TABLE I
DETAILS OF FAILURES, ETC., EXPERIENCED

Boiler No.	Date Welded	Description of Welding	Date of Failure	Time in Service (months)	Subsequent Repairs and Remarks	
8006	8.46	Patch in L.H. wrapper side	8.47	12	New ½ wrapper side fitted and boiler put back in service.	*
D2284	10.46	Patches in R. & L.H. wrapper sides	10.47	12	This firebox was 9½ years old when welded and constructed of "tough pitch" arsenical copper. The boiler, 18 years old, was scrapped.	†
D143	6.46	Patch in R.H. wrapper side	10.47	16	Larger patch fitted and boiler put back in service.	*
1239	9.45	Patch in L.H. wrapper side	10.47	25	New ½ wrapper side fitted and boiler put back in service.	‡
1081	10.46	Patches in R. & L.H. wrapper sides	11.47	13	X-ray revealed defects. New firebox fitted.	*
985	12.45	Patches in R. & L.H. wrapper sides	1.48	25	New ½ wrapper sides fitted and boiler put back in service.	‡
843	3.46	Patches in R. & L.H. wrapper sides	1.48	22	Do.	‡
3854	5.46	Patches in R. & L.H. wrapper sides	1.48	20	Do.	‡
964	8.46	Patches in R. & L.H. wrapper sides	1.48	17	Do.	*
4914	8.46	Patch in R.H. wrapper side	12.47	16	X-ray revealed defect in old plate at junction of weld. Larger patch fitted and boiler put back in service.	*
902	2.47	Patch in L.H. wrapper side	1.49	23	Fracture in weld, serrations between stay holes; plates bulged in lower area, crown bulged. Boiler had been heavily worked. New firebox fitted.	§
727	1.47	New ½ wrapper sides fitted	5.49	28	X-ray revealed fractures developing in R.H. wrapper side. Firebox generally in run down condition. Boiler 18 years old was scrapped.	§
3737	4.47	Patch in L.H. wrapper side	12.47	8	X-ray revealed fracture at weld. New ½ wrapper sides fitted and boiler returned to service.	*
326	6.47	New ½ wrapper sides fitted	9.49	27	X-ray revealed fracture in R.H. seam which was re-welded and boiler put back in service.	‡
4256	1.46	New ½ wrapper sides fitted	8.49	43	Do.	§
3210	1.47	New ½ wrapper sides fitted	8.49	31	X-ray revealed wasted seams and fractures on water side. Firebox renewed.	§
3422	2.48	Radii of tubeplate flanges reinforced	11.49	21	Grooving not completely removed before welding causing contractional fracture on water side and subsequently failure of weld. New tubeplate fitted and boiler returned to service.	*

* 7 which failed to give service expected.
† 2 considered failures = 0.3% of total fireboxes welded.
‡ 4 gave reasonably good service only.
§ 4 gave service expected.

SUMMARY

	1944	1945	1946	1947	1948	1949	
Total fireboxes welded	29	59	111	147	120	125	=591 total

bridges of which have been continuously stressed due to expanding and re-expanding of tubes in bad water districts. It is acknowledged that it is perfectly possible to produce good tubeplate bridge welds where the parent metal has not been mechanically ill-treated in service, and on both the Western and London Midland Regions this form of repair is carried out successfully by using an electrolytic copper filler rod.

FAILURES

The total number of fireboxes repaired by welding up to the end of 1950 was 700, and of these some 17 were considered failures, i.e. just over 2 per cent. The word "failure" is perhaps a misnomer and was used to indicate that the fireboxes did not run the complete period between general repairs or a weld leaked whilst in service; comparatively "light repairs" were required in most cases, such as cutting out and rewelding. Table I shows the original and subsequent repair in each case.

WATER SPACE STAYS

The extremely bad water conditions which have prevailed on the Great Central Area of the British Railways have always caused excessively heavy maintenance repairs to the boilers of engines passing through the Gorton Locomotive Works. Difficulty in preventing leakage of scale impregnated water through the stay threads and into the copper firebox interior, has been a problem for many years and though careful inspection and maintenance of screwing and tapping equipment has assisted in the matter, penetration, however, still occurs, and in the case of engines located in certain districts it has resulted in constant but ineffectual hammering of the leaking stays with subsequent premature renewal of stays and plates in main works.

Figure 10 shows a radiograph of a normal screwed stay inserted in a copper plate, the radiograph having been taken accurately through the centre of the stay. The usual tolerances (air gaps) are seen at the top and bottom of the threads, it is this gap between stay and plate which must be permanently sealed to avoid leakage.

The leakage of water from a riveted stay can only take place when the head of the stay is not firmly pressed on to the plate. Unfortunately, as is well known, the stay head, presenting an easy target for flame action, is being continually reduced in size and distorted in shape by burning, so that frequent hammering up of stays must take place at motive power depots. It appeared that seal welding of the stay would not only prevent leakage, but at the same time would eliminate the protruding head.

Tests were, therefore, carried out on stays screwed flush into pieces of plate, i.e. without heads and pulled to destruction, together with stays screwed flush into plate and welded, and stays screwed into plate and riveted over in the normal way. These tests showed that the screwed stay with or without head, has an ample margin of strength longitudinally.

The results of this research seemed to justify experiments with an actual firebox and to date some ten fireboxes have had the stays in the

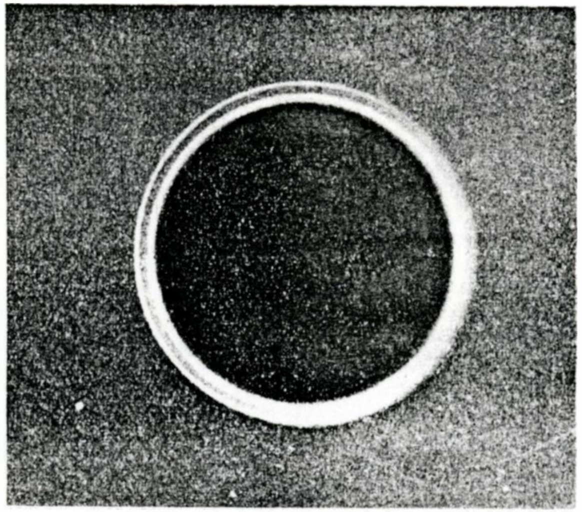


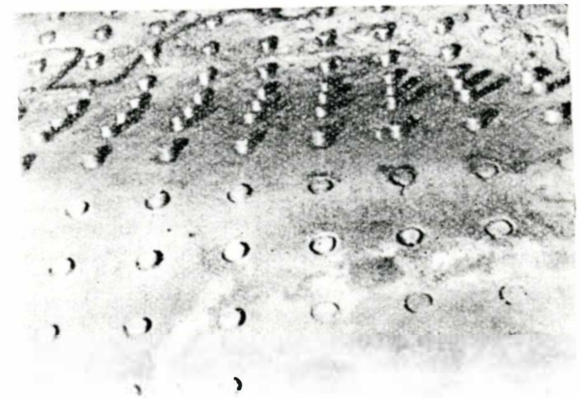
FIG. 10

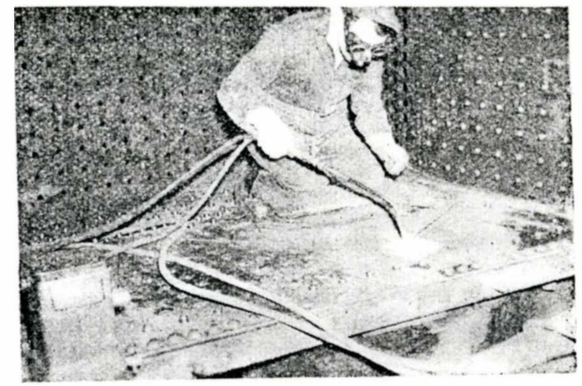
RADIOGRAPH OF SCREWED STAY IN A COPPER PLATE SHOWING TOLERANCES (AIR GAPS) AT TOP AND BOTTOM OF THREADS

fire area of the wrapper side, either left or right or both sides, seal welded. Some of these fireboxes have been in service up to 18 months, one actually being in service for two years, and reports so far indicate that the experiment is proceeding satisfactorily.

Figure 11 gives some idea of the preparation for welding. It will be seen that there is a groove around the flush stay ends. This is a deliberate countersink preparation for welding, forming a pool to collect the molten copper during the pre-heating operation. Fig. 12 shows the actual operation of stay welding and Fig. 13 shows a portion of a side-plate having welded stays, from which it will be noticed that there are light identification pop marks on the firebox plate itself. These are for the purpose of picking up the centre lines of the welded stays. It will be appreciated that when these welded stays are in service it is essential to locate their position accurately, so that the normal hammer testing at motive power depots can be carried out just as easily as with the visible riveted stay. Once, therefore, the centre of the stay has been found from the pop marks, a punch is used to mark this spot. The punch is $\frac{3}{16}$ in. diameter and is driven into the welded stay for $\frac{1}{4}$ in.; these stay centre indication holes do not become clogged up with soot in service.

Figure 14 shows a firebox wrapper side with 155 stays welded, in a G.C. 2-8-0 0.4 class boiler. It is interesting to note that when the first firebox of this class was welded it was found that both the copper plate and the steel wrapper plate had bulged to such an extent that the foundation ring was also slightly distorted. On looking into the reason





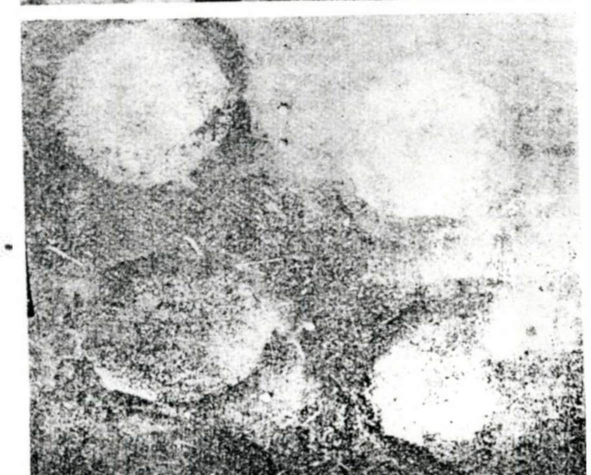


FIG. 11 (*top*) GROOVES ROUND STAY ENDS PREPARED FOR WELDING
FIG. 12 (*centre*) OPERATION OF STAY WELDING
FIG. 13 (*bottom*) PORTION OF A SIDE PLATE HAVING WELDED STAYS

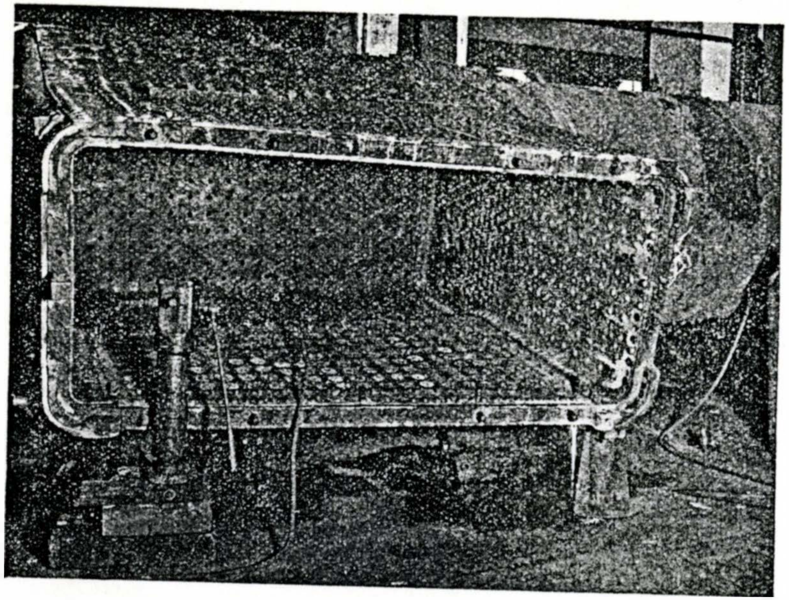


FIG. 14

FIREBOX WRAPPER SIDE HAVING 155 STAYS WELDED. G.C. 2-8-0 0.4 CLASS BOILER

for this it was originally felt that the sequence of welding the stays had some effect due to localising the heat in the centre of the plate, but experiments proved this assumption to be wrong. In practice the altered technique did not bring about the desired results, the problem being one of contraction causing distortion, this distortion being due to the very high heat input over a much increased area of firebox than the small boilers previously dealt with. The bending moment induced in the copper and steel plate being considerably increased because the supporting points, viz. the tubeplate and doorplate, were at a greater distance apart. The distortion had nothing to do with the actual welding of the copper stays, but was due to the high heat input of the acetylene method of welding.

This problem of welding the stays in long fireboxes has been successfully overcome by using running water, in the water space, as a cooling medium, the boiler being laid on its side, water being allowed to run into the water space but not of such a depth that it touches the copper plate. This was easily arranged by the introduction of a jack supporting the foundation ring which is raised and lowered according to the row of stays on which welding is being done (Fig. 14). One interesting feature of this successful method of welding copper stays in large fireboxes is that considerably more gas is used in the welding process.

Another successful method welding copper stays which would avoid the buckling of plates would be to deposit firebox quality copper at a much greater speed, for example, by the Argon Gas process, and

some reference to this will be made later in this Paper under "Better Methods of Welding."

SAVINGS RESULTING FROM COPPER WELDING REPAIRS

It was only to be expected that substantial savings would accrue when the repairs of fireboxes by welding had become an established fact. The results shown in Tables II, III and IV fully confirm this and justify this time and trouble taken to perfect the process. The details cover only for Direct Wages and Material Costs.

The first cost of seal welding stays is, of course, much higher than similar cost for riveting, and, therefore, care should be taken only to seal weld stays in the lower portion of the side and back plates. From evidence already obtained there would appear to be not the least doubt that seal welded stays require no attention at first heavy general shopping; further, there is every hope that no attention will be required at the second heavy general shop repair. Assuming, however, that only one heavy general is eliminated, and, taking as an example a comparatively small boiler having only 250 seal welded stays, and estimating a weekly output of six such boilers, on which there is a saving of £42 per boiler, or approximately 45 per cent. of the present cost of repair, then taking these figures over a four-yearly period, the direct wages savings would be approximately £12,000.

For larger boilers up to 350 stays the savings would be correspondingly greater. See Table V.

X-RAY

The Author, in order to achieve maximum efficiency and soundness of weld, sought for some means of non-destructive testing and decided that X-ray equipment was the most suitable means for bringing

TABLE II

DETAILS OF SAVINGS

Year ending 31st December 1947

Copper Welding Carried Out	*Nett Cost* £	s.	d.	*Repairs Rendered Unnecessary*	*Nett Cost* £	s.	d.
(3) One half wrapper side	184	18	2	New firebox	1499	14	9
(29) Two half wrapper sides	2602	7	0	New firebox	14497	9	3
(7) Patch on wrapper side	205	9	3	New firebox	2999	9	6
(42) Firehole reinforced	96	4	1	Firehole patch	735	10	6
(9) Firehole reinforced top ½	21	4	7	½ firehole patch	113	6	9
(12) Firehole and tubeplate or doorplate radii reinforced	55	16	10	Firehole and flange patches	539	8	11
(17) Tubeplate and/or doorplate flanges and radii reinforced	101	15	7	New plate and flange patches	1669	8	5
(27) Pieces in tubeplate and/or doorplate flanges	139	7	2	Flange patches	1144	7	4
(1) Caulking impression	5	1	3	--			
Welding rod	130	0	0				
Oxygen	89	0	0				
Acetylene	283	0	0				
	3914	3	11		23198	15	5

TABLE III

DETAILS OF SAVINGS

Year ending 31st December 1948

Copper Welding Carried Out	*Nett Cost*	*Repairs Rendered Unnecessary*	*Nett Cost*
	£ s. d.		£ s. d.
(1) One half wrapper side	50 12 6	New firebox	499 18 3
(17) Two half wrapper sides	1757 1 5	New firebox	8498 10 3
(2) Patch on wrapper side	52 7 6	New firebox	999 16 6
(21) Firehole reinforced	56 17 0	Firehole patch	367 15 3
(17) Firehole reinforced top ½	40 5 9	½ firehole patch	250 19 3
(5) Firehole and tubeplate or doorplate radii reinforced	24 8 0	Firehole and flange patches	190 0 8
(35) Tubeplate and/or doorplate flanges and radii reinforced	235 13 8	New plate and flange patches	4772 1 3
(13) Pieces in tubeplate and/or doorplate flanges	39 2 8	Flange patches	375 13 7
(4) Hind wrapper crown radius and top ½ firehole reinforced	31 17 4	½ firehole patch	44 5 9
(5) Caulking impression	10 12 0	—	
Welding rod	165 1 9		
Oxygen	51 10 0		
Acetylene	171 5 0		
	2686 14 7		15999 0 9

TABLE IV

DETAILS OF SAVINGS

Year ending 31st December 1949

Copper Welding Carried Out	*Nett Cost*	*Repairs Rendered Unnecessary*	*Nett Cost*
	£ s. d.		£ s. d.
(2) One half wrapper side	114 1 10	New firebox	999 16 6
(9) Two half wrapper sides	926 7 5	New firebox	4491 4 3
(2) Patch on wrapper side	58 5 10	New firebox	999 16 6
(28) Firehole reinforced	64 16 4	Firehole patch	489 18 3
(37) Firehole reinforced top ½	83 16 1	½ firehole patch	551 14 3
(8) Firehole and tubeplate or doorplate radii reinforced	48 9 1	Firehole and flange patches	413 6 8
(14) Tubeplate and/or doorplate flanges and radii reinforced	77 16 10	New plate and flange patches	1331 9 8
(22) Pieces in tubeplate and/or doorplate flanges	106 12 11	Flange patches	837 3 10
(2) Caulking impression	4 10 0	—	
(1) Stays welded—part lower ½ wrapper—one side	15 16 0	Stays riveted	10 5 11
Welding rod	162 4 0		
Oxygen	49 10 0		
Acetylene	165 10 0		
	1877 16 4		10124 15 10

TABLE V

DETAILS OF SAVING ON STAY WELDING

Copper Firebox Stays

Comparative Statement of Costs

(1) 250 stays riveted in both steel and copper plates.
(2) 250 stays riveted in steel plate and welded in copper plate.

Initial cost—New firebox or firebox in good condition—	*Cost per boiler* £ s. d.
(1) Riveted construction	33 8 8
(2) Welded construction	49 19 8
Difference in favour of (1) riveting	16 11 0
Cost when first restay is required—	
(1) Riveted construction	61 6 8
(2) Welded construction	2 12 1
Difference in favour of (2) welding	58 14 7

SUMMARY

(1) Initial cost of fitting 250 copper stays riveted in both steel and copper plates + cost of changing 250 stays at first re-stay	94 15 4
(2) Initial cost of fitting 250 copper stays riveted in steel plate and welded in copper plate + cleaning of the same stays when re-stay would normally be required	52 11 9
(3) Difference in favour of (2) welding, i.e. at the first re-stay	42 3 7

this about. Accordingly a Phillip's 150 Macro Unit was purchased. This X-ray Unit was mounted on a chassis of an old 30 cwt. motor and, subject to obvious limitations, is able to be moved wherever required in the shops. See Fig. 15. Every firebox which has had a portion of the plates cut and new sections let in is radiographed; these radiographs are examined by the welding specialist so that the boiler shop foreman is not left in any doubt as to the quality of the welded joints. 100 per cent. perfection of joint is aimed at and it is surprising how difficult this is to attain. Fig. 16 gives some idea of the type of defects which can occur even with experienced operators, and it should be realised that to make a 100 per cent. weld the applied metal from the filler rod should be molten and deposited on the parent metal when the parent metal is also molten and this process kept going continuously.

It can be said that a large number of defective welds are occasioned by the parent metal being barely plastic at the time the molten filler rod is introduced, or, alternatively, that both the filler rod and the parent metal are too hot, too fluid. The importance of this cannot be overstressed in connection with the welding of stays where there is no great depth of weld (Vee) and, therefore, no possibility of corrective influence in succeeding layers.

The value of an X-ray equipment is not only confined to the examination of new welds made in fireboxes, but considerable value can

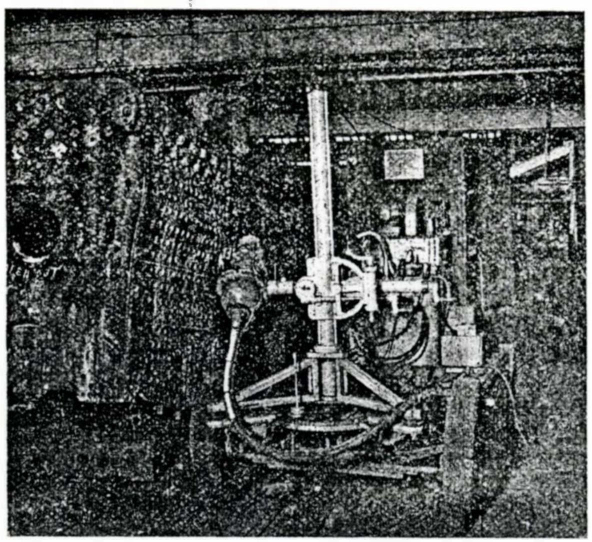


FIG. 15

PHILLIP'S 150 MACRO UNIT MOUNTED ON 30 CWT. MOTOR CHASSIS

be derived from an examination of a firebox which is thought to require new steel plates (and naturally a good boiler shop foreman desires to be on the safe side), whereas by radiographing and thereby seeing the actual condition prior to undertaking repairs it can be definitely decided whether a plate is in fact sound or otherwise. It is the Author's view that each main works on British Railways, where frequent and heavy boiler repairs arise, should be provided with X-ray equipment and staff.

TRAINING AND TESTING OF WELDERS AND SUPERVISION

Experience has shown that welding operators who have had no previous experience of welding of any kind are the best operators. It may take longer to train them, but they do not have to unlearn. It is an advantage if the type of people chosen for copper firebox welding have had boilermaking experience because they are to some extent aware of the type of duties their finished work will have to perform and just what relationship their part of a repair bears to the rest of the job. It follows, therefore, that where a variety of work is carried out, it is necessary regularly to test the operators and it is standard practice for each operator to weld every three months test plates for tensile and bending tests, and for the operators to see the radiographs of these test pieces and discuss defects, etc., with the welding specialist. This has the effect of promoting keenness and insight into the job.

Adequate supervision is absolutely vital if 100 per cent. weld, or as near as possible, is to be obtained. The need for this specialised supervision, coupled with a factor which one does not find referred to in textbooks, namely "heat fatigue," to which operators are prone

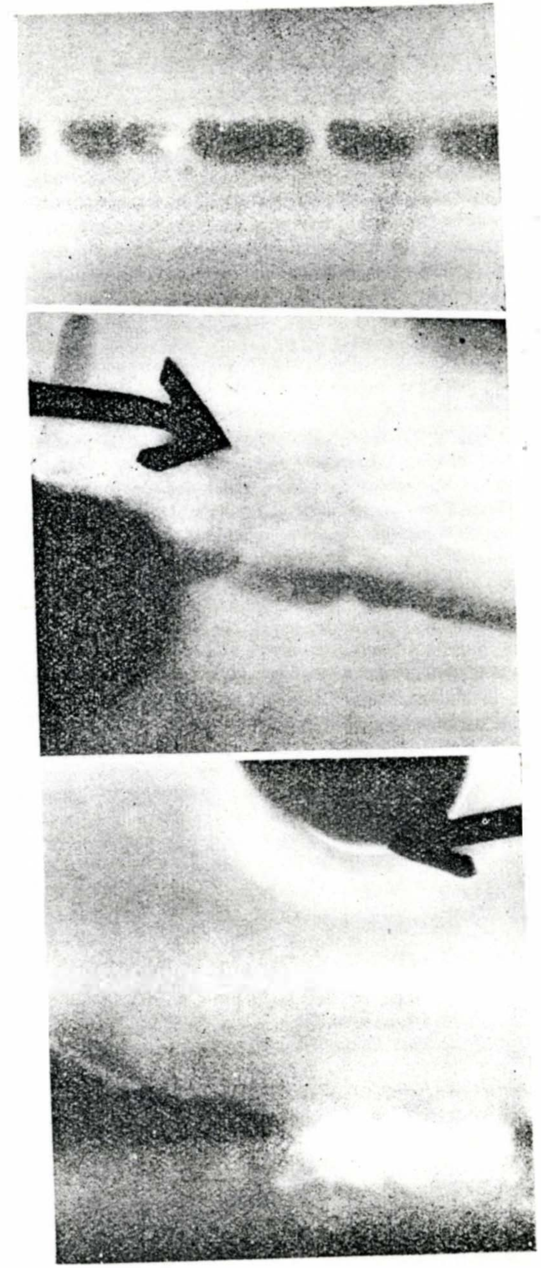


FIG. 16

X-RAY SHOWING DEFECTS IN WELDS

particularly when working on long seams or in confined spaces, raises the vital question of the method of payment to the operator.

Piecework, or payment by results, cannot, in the Author's view, be considered as a suitable medium of remuneration to the operator, as the "best result" to be obtained can only be achieved by experience and careful supervision. Speed, in fact, is detrimental to the weld, since both the parent metal and the filler rod must remain in a molten condition together, and these conditions can only be obtained if careful thought and no question of speed is given to the matter by the operator. Further, each operator must be given periods of time off duty, during which off duty period the welder assists the gang, and this ensures that heat fatigue does not become a serious problem. In other words, there is only one period of time for carrying out a particular welding operation; if the time is lengthened or shortened, the physical result obtained is not, and cannot be expected to be, 100 per cent.

Copper welders, in the Author's view, should be paid a wage comparable with what they would earn under normal circumstances.

BETTER METHODS OF WELDING

The oxy-acetylene welding process has its limitations in that heat input of the article to be welded is high, which in terms of expansion and contraction can be a major problem in itself. It has come to the Author's notice that a new process is being used and further developed in the U.S.A. whereby de-oxidised copper, and for that matter, "tough pitch" copper, can be deposited by the electric arc process within the protection of an envelope of Argon gas*, the rate of deposition being about five times as fast as that of the oxy-acetylene process, and accordingly the heat input would be considerably less than that of the oxy-acetylene process. It is felt that as and when this process is available for use in this country further great strides may be made towards the saving in the effective use of copper for locomotive fireboxes, and the Author is pursuing this aspect.

Briefly this process is a combination of gas and arc welding. The electrode is consumable as with the normal arc welding process, but the diameter of the wire is very much smaller and the currents used are about four times as high. The gases used are either Helium or Argon, or a combination of both, and the special value of this process is that non-ferrous metals such as copper, brass, leaded bronzes, aluminium, magnesium and electron metals can be successfully welded.

In particular, its use in copper stay welding would considerably expedite this process, and to a large extent remove any tendency to buckle the firebox plates in large fireboxes, and it is felt that use of cooling water may be eliminated, thus saving time and gas.

SUGGESTED FUTURE DEVELOPMENT

The cost of shop and shed repairs to locomotive boilers is equal approximately to 30 per cent. of the total cost of repairs to the locomotive and tender, and of this amount it can be said that some 30 per cent. or 10 per cent. of the total cost is concentrated in the firebox of the boiler.

* Known as "Inert gas shielded metal arc" method.

The main items of repair to a boiler can be summarised as follows:—

Defective tubes.
Defective plates and flanges.
Defective side stays.
Defective crown stays.

The initial weaknesses which bring about the defects mentioned above are generally one of the following:—

Leaking of tubes.
Leaking of stays.
Leaking of plate flanges.

An all-welded firebox, including welded stays, eliminates the leakage of two of the above sources of trouble, namely, plates and stays.

It is thought that boiler flue tubes, both large and small, having monel metal or some such readily weldable tube ends at the tubeplate end only, could also be welded to the copper tubeplate, thereby eliminating every source of leaking within the firebox, except foundation ring rivets.

If development proceeds on these lines and it becomes possible to produce a locomotive boiler firebox which gives practically no trouble at motive power depots and requires considerably less repairs in the main shops than at present, then the steam locomotive as a prime mover will have placed itself, from an efficiency point of view, far in front of its principal rivals—the diesel electric and the gas turbine locomotives.

ACKNOWLEDGMENTS

The Author wishes to thank Mr. R. A. Riddles, C.B.E., Railway Executive Member for Mechanical and Electrical Engineering, for permission to read the Paper.

He also wishes to acknowledge the immense help and assistance he has received from the staff at the Locomotive Works, Gorton, Eastern and North Eastern Regions, and, in particular, to thank Mr. G. A. Lockley for the work he has carried out in the general development and control of copper welding.

DISCUSSION

Mr. K. J. Cook, O.B.E. (V.P.) said that the subject was of great importance, a fact which was emphasised by the figures quoted by the Author showing the proportion of cost incurred by locomotive fireboxes in relation to locomotive maintenance as a whole. Therefore, any item which could be fixed upon and any method which could be introduced to reduce that overall cost was one of very great importance.

It would probably be agreed that where any form of development of copper welding took place it would be very difficult to lay down a uniform technique, and where two or three individual sets of people developed a technique of copper welding, they would probably reach the same result by rather different means.

One case where that first became noticeable was that of the filler rod. The Author appeared to favour silver content which, in theory, was probably quite correct, the main feature being that it was more fluid at the same temperature than pure copper. Nevertheless, Mr. Cook suggested that within a certain technique pure electrolytic copper could be developed to the same pitch of efficiency. The silver bearing rod was introduced on the Continent in the early days of copper welding under a proprietary name, and it was rather regarded in some quarters as being a selling point rather than a technical necessity.

With regard to the welding in of copper side plates, the Author employed the silver-content filler rod with intermittent welding, that is, welding a length of about 6 in. then hammering and taking on another section. Mr. Cook suggested that there was another technique for welding in copper side plates which was capable of higher development. It was that referred to by the Author and enabled a complete seam in one to be made in one uninterrupted run. If properly controlled it offered an advantage in that it was possible to weld in a plate already drilled for stay holes, and the welding process ensured its final correct position.

The Author referred briefly to this method of using a copper backing strip which became fused with the metal of the parent and new plates, together with the filler metal, and then became part of the seam. With that technique pure copper filler rod gave 100 per cent. strength from a boiler point of view. It also had another great advantage in that the $\frac{3}{16}$ in. groove formed in the copper backing strip gave a clear indication that welding was proceeding at the correct speed. The new plate was set with a $\frac{3}{16}$ in. gap—line and line with the groove in the backing strip at the starting point—with an increasing gap of $\frac{3}{16}$ in. per foot along the length of the seam. As welding proceeded the plate closed in. If the loose plate tended to close in over the groove it indicated that welding speed was too slow; conversely welding was proceeding too fast if the plate did not reach the edge of the groove.

Recalling a particular incident where this weld was put to an unexpected test, he referred to a case in the recent war where a boiler which had had seams processed by that method was the victim of enemy attack. A fragment of bomb pierced the steel casing, lodged in the copper plate, produced a beautiful " egg " in the latter plate, stretched the adjacent stays by as much as $\frac{3}{8}$ in. but the deformation terminated entirely at the weld which remained unimpaired.

The Author had very rightly introduced the subject to the Institution. It might possibly be thought that there was not a great deal of copper welding being applied to locomotive fireboxes, but it was worth mentioning that on one region in Great Britain there were at least 2,500 locomotives running with fully welded seams in the copper wrappers. As to whether the desirable aim was for completely welded fireboxes or not, it was a matter which must be considered in relation to the maintenance of fireboxes as a whole. He suggested that unless it was the practice to endeavour to carry out light repairs and maintain fireboxes in service until the whole firebox required renewal, it was probably doubtful whether the completely welded firebox would be beneficial. If, however, it were a question of renewing copper side plates with or without tubeplates and backplates, then it might be that a combination of both welded and riveted construction was ideal.

The Author concluded that in the matter of cracked meshes of tubeplates sometimes a mechanical repair was better than a weld, but Mr. Cook had not seen a mechanical repair which he would call complete.

Mr. R. C. Burt (V.) (British Welding Research Association) said that the Author had referred to the Argon process in the course of his paper. The speaker had recently carried out some Argon-arc welds in $\frac{9}{16}$ in. thick copper firebox plate for the Southern Region, British Railways. It was a short series of experiments in order to explore the practicability of the Argon-arc process as a workshop process in welding copper firebox plate. It was gratifying to report that the experiments were very promising to say the least.

There were two types of inert gas shielded welding processes. There was the one which was known in this country as the Argon-arc process, in which a non-consumable tungsten electrode was used which was surrounded by a shield. Through the shield, an inert gas (Argon in this country and Helium also in the United States), was passed and it shielded the arc and the weld from contamination by air thus preventing oxidation. The second type was generally known as the " Aircomatic " process. In that process the electrode was in the form of small gauge wire and it was fed automatically through a shield of inert gas. The electrode holder was in the shape of a gun. This process had some very interesting characteristics. High current densities were used on the small diameter wires with the result that the metal transfer was more in the form of a spray than a globular transfer, and the arc was also to a very large extent self-adjusting. If the arc tended to lengthen, the burn-off rate automatically decreased and would continue to do so until normal arc length was reached. Conversely, if the arc length tended to become too short, the burn-off rate increased until a stable condition was once again reached. This was a most valuable feature which provided more of less automatic welding. His association had one of the few plants available in this country and had recently demonstrated the process in experiments on aluminium and light alloys. When that programme was concluded it was hoped that some welding of copper would be carried out.

The Argon-arc process was essentially a down hand position process and manipulation was similar to that of oxyacetylene welding. Dealing with copper, in any other position than the downhand was difficult because the molten metal was very fluid. It was possible to have a very high rate of heat input and the heat was much more localised than in the oxyacetylene process. At the same time welding speed was much faster. The aircomatic process could be used not only in the downhand, but also in the vertical and overhead positions.

The welds were carried out on $\frac{9}{16}$ in. copper firebox plate supplied by the Southern Region and were done in a single run. Two

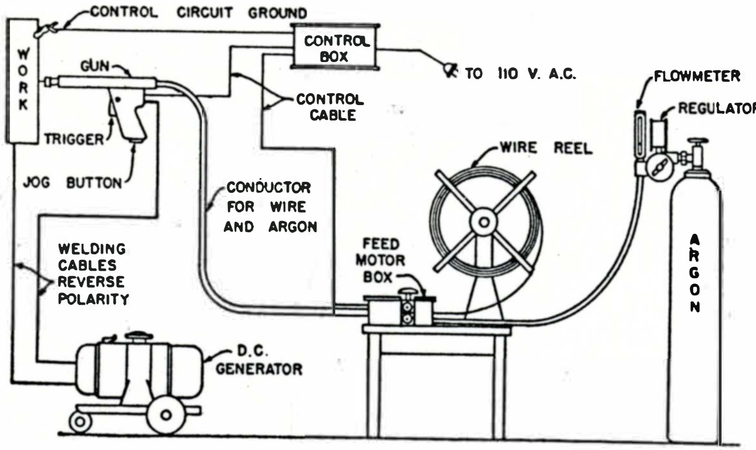


FIG. 17

THE AIRCOMATIC PROCESS

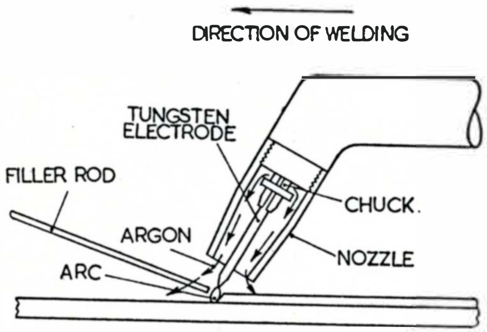


FIG. 18

THE ARGON-ARC PROCESS

preparations were used for the butt weld; one was a single vee of between 60° and 70° and the other was a square edge preparation which gave an appreciable saving in filler metal. This test represented a butt weld such as would be used in fitting a new half or three-quarter wrapper plate. A technique was also tried which simulated the welding of a crack between two tube holes, but that was not quite so successful. It was felt, however, that with further experimenting more successful results could be obtained.

The other trials made were concerned with building up worn flanges and there the method was very successful. To overcome the difficulty of very fluid metal, carbon blocks were used to dam back the weld metal both on the edge of the plate and where holes came for rivets etc. When the weld was dressed off these holes did not require touching up in any way.

With regard to the type of filler used, Argon-arc welding was developed in this country for welding stainless steel, aluminium and

light alloys, but up to the end of 1949 it was not very successful for welding copper. The welds tended to be porous. One research worker in his association carried out tests with different types of filler rod, however, and he found that by using filler containing silicon and manganese as deoxidisers in place of phosphorus, better welds were obtained. The preferred composition was 0.25 silicon, 0.75 tin and 0.15 manganese. At the time the welds on the firebox plate were done it was not possible to get any wire of that particular composition for use as filler rod, so Everdur wire which had a content of 3 per cent. silicon was used and it produced excellent results. It was significant that with the silicon bearing filler rod better results were obtained than with a rod containing phosphorus. The use of phosphorus as a deoxidiser in the plate did not seem to matter, but it did seem to matter in the filler.

Mr. R. C. Bond (V.P.) said that it was not always the case that a good engineer was able or willing to give an account for the benefit of his colleagues of original work which he had done. He had known the Author as a good engineer and railway man for many years, but it was the first time that he had experienced the pleasure of meeting him in the guise of a successful author.

As Mr. Cook had observed, the use of copper welding for repairing locomotive fireboxes was not new. To a large extent, it could be regarded at the present time as a standard method of repair. The only item of repair not yet in general use was the seal welding of copper stays, for the development of which credit must be given to the Author. It was perfectly true that the quality of water supplies on the old Great Central were very bad indeed, but other parts of the British Railways system had to contend with water conditions almost as bad. Some years ago the whole problem was vigorously tackled, the four main line companies initiating a research to find out what could be done to extend the time and mileage between repairs of fireboxes.

One of the first things was to decide what really was the cause of stay wastage. On page 185 the Author stated: " Unfortunately, as is well known, the stay head, presenting an easy target for flame action, is being continually reduced in size and distorted in shape by burning." The use of the word " burning " was not quite correct; and some misconception as to the true cause of stay wastage may be the reason which led the Author to weld the stay heads flush with the surface of the plates. It was true that the initial cause of stay wastage was oxidation, but provided the oxidation occurred under dry conditions, it was not serious. What did make it serious was leakage which occurred mainly at low pressures when the firebox was cooling down. This was caused initially by plastic deformation of the copper plate and stays under working temperatures and pressures, resulting in the formation of a small leakage path between the threads in the plate and stay, when they contract. The leakage water gets underneath the adherent oxide scale and flakes it off the stay heads and surrounding plate. A fresh metallic surface was thus again presented to oxidation, and so the wastage goes on. It is essential to reduce leakage as much as possible. The use of steel or monel metal stays, fitted with nuts in the firebox instead of being riveted, had been found an effective means of doing this on the L.M.S., G.W. and Southern Railways. If it were accepted that it was the leakage which had to be stopped, he wondered whether the flush finish of the welded copper stay heads was desirable. He thought it would have been better to have left the stay heads $\frac{1}{8}$ in. to $\frac{3}{16}$ in. above the plate surface so that when the welding was finished it would be possible to see the stays and so avoid the need to indentify them by marking out. The boiler inspector would thus be able to hammer test the stays with greater confidence and certainty that the stay head was being hit rather than the plate. It was important that one should still be able to detect any broken stays with no greater difficulty than in the past and he thought this practical point was one worthy of consideration.

The economies to be derived from copper welding were beyond dispute, but there were one or two points in connection with Table III in the paper upon which some further information would be useful. Details were set out therein of the savings which accrued from various types of repair. The first item in the table compared the cost of fitting one half wrapper side at £50 12s. 6d. with that of a new firebox at £499 18s. 3d. Surely the comparison should be between the cost of fitting one half wrapper side by welding and riveting respectively. There were many fireboxes in service with riveted half sides which gave a very satisfactory performance. Similar remarks apply in the case of other types of repair for which comparison had been made of the cost of fitting new fireboxes.

In referring to the type of man most suitable to do copper welding, the Author stated that it was better that the man should previously have done no welding at all. That was probably right, but the Author also emphasised the desirability of the man having had boiler making experience. One would have thought that, under present conditions, no one but a fully skilled boiler maker would be allowed to do the work.

In looking forward to the future there was no doubt that anything which could be done to improve the mileage between shops (and it would be interesting to know how much more between shops the Author was getting out of the fireboxes with welded stays) and to reduce the number of shed boiler makers, were steps in the right direction. Notwithstanding all that was said to the contrary, there were great advantages in using copper fireboxes. At the present time, a life of nearly a million miles was being obtained with some copper fireboxes. Anything further which could be done by welding tube ends, stays and seams, would provide valuable experience. It might ultimately be found, however, that the best results would be obtained from a firebox partly welded and partly riveted.

Mr. S. Wise (V.) said that a large number of people had attempted to seal weld stays in the past, but usually they had been unsuccessful and it was interesting to hear that success had been achieved in that respect by the Author.

The Author's use of X-radiography as a routine check on weld quality was to be welcomed, but it should be pointed out that one of the most serious defects in copper welds—intergranular films of copper-cuprous oxide eutectic—could not usually be detected by X-radiography, and that intergranular films could be easily formed either by bad manipulation of the blowpipe or by the use of a blowpipe with an excess of oxygen in the flame.

With regard to the section of the paper Better Methods of Welding, the Southern Region Research Section which was partly responsible for the development of copper welding in Ashford Works was very interested in other methods. In the years since the war most of the arc welding procedures had been tried, but nearly all of them had proved disappointing. The Research Section had always wanted to try the Argon-arc process but it was not possible because there was no commercial equipment available in this country for Argon-arc welding of copper in thicknesses more than $\frac{1}{4}$ in. A few years ago, however, in the course of a discussion with the British Welding Research Association, his Section was told that the B.W.R.A. had equipment capable of producing 750 amps, or thereabouts, which they thought would be capable of welding $\frac{9}{16}$ in. copper. Some joint tests were therefore arranged, the Southern Region supplying the copper plate and the Association carrying out the welding. The work had been completed and a report had been issued. It was hoped that full details would be published in the transactions of the Institute of Welding.

Mr. Burt had given some general idea of the principles of Argon-arc welding, but it might be of interest to know that which the Southern Region did.

They had butt welds on $\frac{9}{16}$ in. copper made in 60°V preparations from the close section butt, welded on one run. The sections were cut up for microscopic examination and were found to be quite sound and free from porosity or intergranular oxide film. The plates were radiographed before being cut up, and perfectly clear radiographs were obtained except where penetration was not complete. That was probably due to the operator who was not experienced in that class of work. The plates were then bent cold and absolutely no trouble was experienced in taking them round to 180° without cracking. That said much for the quality of the weld. The British Welding Research Association also tried to weld some cracks in the middle of copper plate but were not successful. Building up was then tried and the results were very good. The edges were dammed up with carbon blocks and the surface of the weld was very level. It would not need any noticeable amount of chipping and the holes were perfectly sound once the carbon blocks were taken out.

In the case of badly worn flanges it was possible that the process might run into difficulties. But if wear on the flanges was arrested at an early stage, it was a very good method of producing a clean sound weld with a minimum of after work in putting the rivets back and putting the plate into service again. Again, as the Author had pointed out, the whole process having such a concentrated heat supply, it looked like overcoming many difficulties associated with the ordinary oxy-acetylene process.

Mr. R. C. Burt (V.) added that the torch used on the welds was not a commercial torch but was designed and made by his association because there was no commercial torch available of sufficient capacity.

It was designed for 600 amps but had been used for more than 750 amps. The shield around the electrode instead of being of ceramic was of copper, water cooled.

Mr. M. A. Crane (M.) referred to the Author's statement that the welded firebox gave a further 4½ years of life which equalled approximately 60 per cent. increased life on an average firebox, and asked whether one was to assume from that statement that the average life of a copper firebox was only 7½ years, bearing in mind Mr. Bond's remarks concerning the mileage at present obtained.

He also asked for some details of the shape of the backing strips. The $\frac{3}{16}$ in. wide groove had been mentioned, and he recalled that in the case of the weld in the crown, when the two wrappers were put together a specially shaped backing strip was used.

Dr. L. J. Haydon (V.) speaking as a medical man, asked the Author whether many welders suffered from nitric oxide poisoning or from metal fume fever. If not, it would be interesting to know whether special precautions were taken. He also asked if the rate of respiratory diseases was high.

Mr. C. F. Rose (A.M.) said that Mr. Bond had touched on a very important point, namely when seal welded stays were used it might be difficult for the boiler examiner to discover whether or not the stay was in fact cracked. It always seemed to be easier to hit something which could be seen protruding than some mark which was in the surface. It would be interesting to know whether the Author had any information on how many seal welded but subsequently cracked stays had been discovered, and whether there was any difficulty in doing so.

Mr. T. Henry Turner, M.Sc. (M.) said that as welding was a borderline subject between metallurgy and engineering, it might be as well to have the metallurgical point of view.

Twenty-five years ago all the British railways were using tough pitch arsenical copper for fireboxes, and then the Great Western introduced de-oxidised copper. When Mr. Turner heard that he passed on the information to Sir Nigel Gresley who was not then interested in firebox copper welding. However, Sir Nigel had the foresight to change the specification and introduce the use of de-oxidised arsenical copper so that welding could be done in the future if desired. Thus, when the Author was moved to do something about copper firebox welding, there was a fair quantity of de-oxidised arsenical copper upon which to start.

The subject of the paper deserved more consideration by locomotive engineers in this country than elsewhere, because of the many thousands of copper fireboxes in use as compared with the preponderance of steel fireboxes in a number of countries, and the use of steel in stationary and marine boilers.

The Author dealt mainly with his practical development work at Gorton. There was no doubt that had it not been for the Author's [illegible]tiative, very little copper welding would have b[illegible] done on the

L.N.E.R. Mr. Turner had looked into the literature, and submitted a short bibliography on the subject which was not without interest, because it started off forty years ago. At that time, when the Institute of Metals was very young, an Italian, Dr. Carnevali, read a paper in which he spoke of his experiments in the oxy-acetylene welding of copper. In those days the difficulties of welding copper were very great because the great thermal conductivity of copper made it nearly impossible to get the intensity of heat needed in the locality of the weld; the copper absorbed gases readily at high temperatures, and copper oxidised and dissolved its own oxides at high temperatures. With the gassed and overheated copper welds then produced, hammering was sometimes of no use at all, and the resultant welds were full of cracks and blowholes.

What factors of the welding of copper had changed to make the Author's paper of practical value whereas Dr. Carnevali only warned of difficulties?

Firstly as regards the nature of the oxy-acetylene flame; this was now controllable, and if a reducing flame were played on to copper which contained oxide, serious cracking occurred inside the copper, quite unrelated to external stresses. Cracking did not occur, however, with a neutral flame and de-oxidised copper, i.e. one to which phosphorus had been added and of which a residue remained. That lesson was driven home to the speaker by the cracking of almost all the copper cable bonds welded to rails in the Manchester/Sheffield electrification when they were first applied. The cracks burst inside the copper, due to the effect of the hydrogen in the flame and the oxygen in the copper, producing steam under explosive conditions.

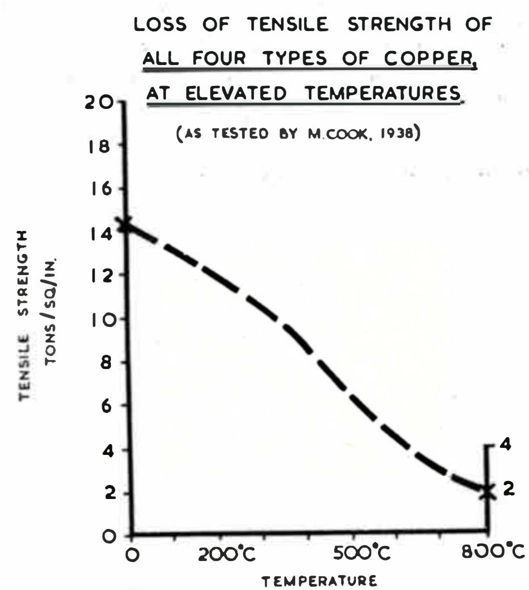


FIG. 19

Secondly as regards the different types of copper; Dr. Cook read a paper to the Institution in 1938 recording tests on four different types of copper, and if we extract from them the tensile properties at elevated temperatures we may produce a curve of the type shown in Fig. 19.

It is important to note that all four varieties suffered a similar loss of tensile strength from nearly 15 tons at room temperatures down to below 2 tons/sq. in. at 800°C.

Thirdly as regards the welding rod there had been a development in the introduction of the silver content and a trace of phosphorus from the metallurgical point of view; but there was also an engineering development in the direction of better welding tools. The welding tools were not available in the early days, and the system of training welders had been much improved. It would be interesting to know whether the Author had carried out any practical trials with annular flames for welding rivets.

The inspection of welds had been helped by the introduction of X-rays which permitted examination below the surface of welds, without destructive testing. However, he agreed with a previous speaker who said that it was not possible to see many little cracks inside the copper by means of X-rays. When he examined one of Mr. Lockley's prototype welds made at Gorton three or more years ago, it was necessary to cut sections from it to find that the welding process had not affected the firebox copper. That method of examination ruined the weld even if it did teach the nature of the metal, so X-rays were of help and the R.E. Research Department's (Metallurgy Division) mobile X-ray coach had been used recently to examine non-destructively welds in copper fireboxes.

The carbon arc welding system had been applied to copper using high amperage, say 400 amps and a high voltage of say 50 volts, and Mr. Chaffee in his paper wrote " No metal can be fabricated more rapidly or at a lower cost than can copper by this method. . . ." So far he understood that method had not been applied to locomotive fireboxes; it might be worth investigating in the workshops.

A SHORT BIBLIOGRAPHY ON COPPER WELDING FOR FIREBOXES

(*Contributed by T. Henry Turner, M.Sc.* (*Member*))

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MEETING IN DARLINGTON 26th MARCH 1952

The Seventh Ordinary General Meeting of the Newcastle-on-Tyne Centre was held at the Imperial Hotel, Darlington, on 26th March 1952, the Chair being taken by Mr. D. W. Hadfield.

The Minutes of the Meeting held on the 29th February 1952, were read, approved and signed as correct.

The Chairman then introduced Mr. J. F. Harrison, who read his Paper entitled " The Application of Welding to Locomotive Boiler Copper Fireboxes.' '

DISCUSSION

Mr. D. W. Hadfield (M.) said that the great value of this method of repair to copper fireboxes obviously lay in the enormous financial savings which could be achieved as compared with the former methods of repair, and he asked if the Author would amplify a few of the details, e.g. copper welding carried out on one half wrapper side costing roughly £51 replacing a repair which formerly would have involved a complete new firebox at £500. It might be due to particular water conditions which would have necessitated the repair being formerly carried out by a complete new firebox rather than to put in a half side riveted patch. In the welded patch the illustrations only showed the horizontal seam welded; were the vertical seams to the backplate and tubeplate flange still secured by the patch studs?

Mr. C. R. Hinds (M.) said he thought that the Author was extremely modest as it took courage to initiate such a technique. People who were responsible for the repair and upkeep of boilers were not inclined to take kindly to new methods. Naturally they played for safety, but it fell to the Author to take the initiative, perhaps under the stress of war-time conditions, to develop a new type of repair. As explained in the Paper, the only people who earlier had done anything of this nature were the G.W. and L.M.S. Railways.

One advantage of welding in plates instead of patching, or else scrapping the plates and putting half sides in, was that one did away with the lap edge joint with its wear and tear under service conditions and its possibility of leakage, which was an important point to be borne in mind. Probably this had not been included in any estimated savings based on the actual results which might be reached in the shed and result in avoidance of days out of traffic, or hours of boilersmiths' attention. This would ensured by the new methods described.

With regard to welding in patches in sides instead of renewing half sides Mr. Hinds asked what experience showed to be the deciding factors. He appreciated that the probable firebox remaining life and its existing plate thickness had to be taken into account, but he noticed in Table I that twelve or nearly 75 per cent., of the 17 quoted so called failures were in connection with patches.

He thought that the Author had hardly done himself credit because, after all, they were not all failures; only two or three were real failures, the other instances did give some further life from the boilers. Actually, no welding done since February 1948 had given trouble, since when, he calculated, 365 fireboxes had been dealt with, which was an excellent figure. Of the fireboxes dealt with up to the end of 1947, which totalled 346, only 16, or roughly 5 per cent., required further attention. This, Mr. Hinds considered, was excellent and reflected great credit on all concerned bearing in mind the whole scheme was based originally on experiment. Furthermore, even the 17 fireboxes mentioned had, as a result, continued in service, he calculated, a further 21 months on an average, so it could not be said that even on these a really worthwhile result had not been obtained.

As regards the alternative of steel backing strip or copper backing strip he understood that the latter was the G.W. method; he asked if both types had been tried at Gorton, or only one, and under which circumstances it was applied.

Mr. Hinds was pleased to hear that the Author thought every Works ought to have an X-ray plant.

Mr. Doran (V.) said a great deal of discretion had to be used when deciding if a job should be copper welded; the physical condition of the box must be taken into consideration to see if it was worth while. In the North Eastern Area, water conditions were not nearly so bad as on the former Great Central and therefore, their capacity for fitting a half sides, did not arise so much as in some areas.

He said that in the process of welding a three quarter or half side, he had adopted the Author's method. Commencing at a point 6 in. from one end and leaving a gap of $\frac{3}{16}$in. to one foot, having continued the welding and reached the other end, possibly 6 ft., he had to go back to the starting point and weld the remaining 6 in. Having done so he noticed there was a tendency to fracture at that point. He asked the Author for his opinion on this matter.

With regard to X-ray plant he thought some authorities considered that once a welder had been brought to a standard of proficiency the X-ray was not always essential, and he thought some authorities accepted this policy.

Mr. D. Reeves (G.) asked if there was any application of this welding of fireboxes without taking them out of the frame. The particular job he had in mind was reeds in the tubeplate. It may be that the vertical welding could not be carried out with acetylene, but the operator in Fig. 4 of the Paper was reinforcing the firehole flan and appeared to be welding in an almost upwar irection.

Mr. F. Johnson (A.M.) asked if the costs of copper welding included the cost of the expert and of the additional welder.

He said with regard to the question of replacement, it appeared that in this area (Darlington) the life of the box was not dependent so much on the corrosion and thickness of the material of the box or side, but largely upon leakage. How would this, therefore, compare with an all-steel firebox with all-steel stays and welded steel tubes, again all flush?

With regard to the present copper stays which were welded flush; he asked if it might not be an advantage to drill tell-tale holes, thereby indicating their centres without pop-making the firebox, such tell-tale holes might also be used to tighten up the stays by expanding the holes.

He asked regarding fitting half sides by welding, if screws were fitted in the riveted joints at the flange plates where riveting was impossible, and also if any trouble was experienced with these, or if plug welding could be resorted to instead of the fitting of screws.

Mr. R. W. Taylor (A.M.) asked where a steel backing strip was employed in seal welding if the water space could be cleaned up after the steel backing strip was withdrawn, so that any running of the weld in the water space could not form a lodging point for sediment.

He asked if a section had been made of a seal welded stay to see how many of the threads had disappeared in the welding process. From the slides it appeared that welded stays have only been fitted in the lower parts of fireboxes where there is the greatest heat and the most trouble experienced with leakage at Motive Power Depots; this position in the firebox, as a rule, being one where broken stays are rarely experienced, *viz.*, frequent leakage, but not breakage, broken stays being usually found in the higher parts of the firebox due to the greater contraction and expansion between the steel wrapper plate and the copper firebox at that point. Would the Author express an opinion as to whether the welded stay would give as good service, without breakage, at the top of the firebox as it would in the fire area?

With the screwed stay there was a certain amount of flexibility in the thread hole which would minimise breakages, whereas if stays are welded at the top of the firebox they may give a less life before fracturing than a screw stay due to the rigidity of the welded stay in the copper plate.

Mr. Gladwin (V.) asked what precautions were taken with regard to expansion to prevent damage and subsequent leakage at adjoining stays or rivets where a welded patch was being fitted.

Mr. A. R. Jefferson (V.) asked if it had been found necessary to renew, either at Motive Power Depots or Works, any welded stays, and if in the course of renewal, probably at a Motive Power Depot, it was satisfactory to fit an ordinary steel stay.

Mr. W. McHugh (V.) said he noticed the Author spoke about fitting half sides in to ld and lightly hammer with pneumatic tools, and he wondered if one could carry out a first aid repair on one of these stays by light hammering, and if the material would stand it.

Mr. Durham (V.) thought that the time had arrived for copper welding to be done in the Motive Power Department, e.g. splits through copper tube plate bridges, bearing in mind they would be strengthened by the beading of the tubes.

Mr. V. Spencer (A.M.) asked what effect welding had on the parent metal.

MEETING IN DONCASTER 27th MARCH 1952

The Sixth Ordinary General Meeting of the North Eastern Centre was held at the Danum Hotel, Doncaster on 27th March 1952, the Chair being taken by Mr. T. Matthewson-Dick.

The Minutes of the Meeting held on the 21st February 1952, were read, approved, and signed as correct

The Chairman then introduced Mr. J. F. Harrison who read his Paper entitled " The Application of Welding to Locomotive Boiler Copper Fireboxes."

This was followed by a discussion.

DISCUSSION

Mr. J. N. Compton, O.B.E. (M.) said he was not quite clear on the half side welding operation and how the contraction depended on the length of run of weld.

Were the majority of fireboxes on British Railways made from arsenical copper plate or were they all now constructed of de-oxidised copper plate?

Mr. Evans (V.) asked if it was essential to use a pneumatic hammer, or if hammering by hand was equally effective after welding approximately 6 in. of copper. Also, when welding a portion into a firehole, was hammering carried out during the operation or afterwards? The reason for the question was the awkward position of the weld—the top portion being near the firebox crown.

Mr. J. Brown (V.) said that he noticed with interest that the work involved such a high degree of skill not suited to piecework conditions and asked what percentage of relaxation for heat fatigue was allowed and what percentage of alternative work had to be found to relieve the men.

Mr. J. E. Owen (V.) asked if the Author considered it necessary to use the copper silver alloy filler rods on the seal welding of stays, or would the plain electrolytic copper rod suffice for this operation as the tensile strength of the rod did not appear to be important in this application?

A table had been shown setting out the savings by welding as compared with the cost of a new copper firebox but did these figures take [illegible]o account the scrap value of the old copper box?

The Author had referred to the possibilities of the Argon shielded arc process. Was any development work proceeding with this process in this country, or were we awaiting the results of American experiments?

Mr. Maddison (V.) remarked that he was very interested in the radiograph showing the thread inaccuracy between the stay end and the mating hole. Was the radiograph taken before or after the stay was riveted?

Had any experiments been carried out on welding a plain stay instead of a screwed stay and seal welded?

Mr. T. Matthewson-Dick (M.) asked the Author to elaborate on the method of testing the welded seam adding that he knew that to prove the weld equal to the strength of the plate the 180° bend test was usually made, but it was not clear why this vicious test was necessary to prove equality of strength.

He asked if there was a definite syllabus for the training of staff in the use of oxy-acetylene torches for copper welding. To indicate the degree of training success he asked what was the expectation of failures in, say, every five men given training.

Mr. D. C. Stuart (M.) said that in the district with which he was associated experience with welded stays was very limited, and he asked if a broken stay would be replaced at the sheds by an ordinary stay or if special arrangements had to be made for replacement by the Works staff. He also asked if a welded stay could be put in with the boiler in the frame.

Mr. K. J. Cook, O.B.E. (V.P.) said in regard to the Author mentioning the essentiality of hammering the seam, he thought it depended upon the technique adopted, and on the Western Region hammering after seam welding was not employed.

Arising from Mr. Compton's remarks concerning the welding of tough pitch copper, it was not impossible to make a satisfactory weld and in fact, many such seams had been made. After a time difficulties were encountered which were considered to arise more from the angle of endeavouring to weld simultaneously on dissimilar coppers. A final changeover was therefore made to ensure that all plates were of de-oxidised copper, and fireboxes built after a certain date were known to be of such and therefore fully weldable. Until this period was reached welding of seams was restricted to boilers carrying a working pressure of 200 lb./sq. in. or less, although a number working at higher pressures had been satisfactorily welded.

MEETING IN DERBY 2nd APRIL 1952

The Seventh Ordinary General Meeting of the Midlands Centre was held at the Midland Hotel on 2nd April 1952, the Chair being taken by Mr. M. S. Hatchell.

The Minutes of the Meeting held on the 13th March 1952, were read, approved, and [illegible]ned as correct.

The Chairman then introduced Mr. J. F. Harrison who read his Paper entitled "The Application of Welding to Locomotive Boiler Copper Fireboxes."

This was followed by a discussion.

DISCUSSION

Mr. M. S. Hatchell (M.) referred to the two methods of welding mentioned in the Paper—the short intermittent runs followed by hammering and a steel backing strip which was removed when the full weld had been completed, and the continuous weld with two welders using a copper backing strip which remained. He asked if the copper strip tended to build up scale, particularly where locomotives were operating in bad water districts.

Mr. C. S. Cocks (M.) said it was very encouraging to find an engineer who had the courage of his convictions, and having been faced with an unsatisfactory condition, did something about it to improve it, thereby progressing in engineering.

He felt that whilst they were wedded to copper fireboxes, it was imperative to prevent copper stays from leaking. It was perhaps unfortunate that steel fireboxes were not generally adopted, as it would then not be so difficult to perform the welding operation.

In connection with the fitting of the copper stays, he asked if they were riveted over on the outside of the steel wrapper before being welded on the inner firebox, or afterwards, since if they were riveted before welding, it would be necessary to leave the stay projecting on the inside of the firebox; it would also be interesting to know how much was the projection.

In view of the Author saying that the copper weld had the equivalent strength of the parent metal, he asked if the ultimate aim was to have a completely welded stay placing complete reliance on the 100 per cent weld.

The Author had said that heat had a lot to do with the question of welding. In view of this Mr. Cocks asked why such a wide angle was used for the weld deposit. The aim surely should be to make the angle of weld as small as was reasonably possible, less heat would then be needed and less metal deposited.

He asked if $\frac{3}{16}$ in. gap per foot run of weld was required, since if the weld was 10 ft. long there would be a gap of $1\frac{7}{8}$ in. at one end. He thought it was quite clear from the Paper that welds followed each other and there was no question of step back welding being used.

Regarding marking off, he suggested it might be better to make a simple template of the staying of the portion of the box in which the stays were to be welded. While the method used by the Author of placing centre pops in convenient places to enable the re-marking of the plate to be done without much difficulty, this method could only be followed where the stays followed a regular pattern, but was of no use for the stays at the forward end of a firebox with a sloping throat plate. In such cases the stays at the forward end followed no regular pattern, but were pitched at regular intervals to stays in the plate between the lap joint and the part of the firebox where regular pa[illegible]n stays commenced. It seemed to him in either case the job

would be more simply and cheaply done by using a suitable template, as such templates could be made to drawing and checked as necessary against each individual firebox.

Mr. M. A. Henstock (A.M.) said regarding tubeplate bridges that from his experience at Derby it was extremely difficult to make a successful job unless the tubeplate were removed from the boiler.

He asked if it was easy to sound stays in the firebox when they had been welded in the way indicated. He thought it would have been difficult with the copper box and copper stays virtually all in one piece.

He said that the savings shown in Tables II, III and IV for "One half side" compared with a new firebox were not a correct comparison, the savings would appear to be rather overstated.

The Author, he said, also mentioned backing strips. He asked if there was any special design for backing strips at Gorton. Was there a machined groove at the back, and was any preparation done to the grooves, since at Derby they found graphiting the strips at the back saved re-machining?

He did not agree with the Author about piecework, because he felt that if piecework prices were set properly, and there was supervision and inspection, good workmanship was obtained in railway workshops. Further, the actual welding time was only about one third of the total time involved.

Mr. G. Walton (V.) said that the reference made by the Author to "piecework" or "payment by results" not being a suitable method of payment for Copper Welders was very pleasing. The statement that speed, in fact, was detrimental to the weld was open to question for the following reasons:—

The success of any weld was surely dependent upon obtaining fusion. This was established in copper welding as a result of the rate of heat input, which was in turn controlled by the capacity of the oxy-acetylene welding blow-pipe employed. Therefore, the higher the rate of heat input, the quicker the operator could obtain fusion and so speed up the welding.

This increase of speed could be established by employing high capacity pre-heating and welding blow-pipes. That in turn would offset the factor "heat fatigue" which was mentioned as undesirable.

Therefore, was it not incorrect to state that there was only one period of time of carrying out a particular welding operation? Surely that was controlled by the rate of heat input, and one could only hope for the use of something like Aircomatic equipment which had a very high rate of heat input, due to its source of heat being the electric arc, which would speed up or shorten the time taken for a particular weld with minimum "heat fatigue" to operators, with corresponding increased efficiency to the resultant weld.

The practice of each operator having to weld, every three months, a test plate for tensile and bend test seemed superfluous. Surely, each actual weld [illegible] a boiler firebox was in itself subjected to test conditions in service.

Mr. G. Foster (M.) said he was interested in the small inserts in wrapper side plates, particularly since the information quoted by the Author in Tables I to IV seemed to suggest that the inserts were not entirely satisfactory. Table I showed a very large number of failures (he used the term in the same way as the Author) for patches or inserts into the wrapper plate, and Tables II, III and IV confirmed this because there was a falling off in the number welded as the years went on. Did the Author feel they were a success or not? It was an extremely important point in view of the fact that on an all-welded copper firebox, any repairs to the wrapper, firedoor or tubeplates must of necessity involve the welding of a three-sided insert, and at least one of the welds would be made under constraint.

Again, dealing with the small inserts, if the area of wrapper plate worn thin was small, then a more attractive method of repair would be to deposit metal on to the wrapper plate instead of inserting a new piece. The length of weld on a small insert was practically equal to that on a half side, and since quite a number of stays were cut out, the wages and the material cost must approach very closely to those for a half side weld. The building up of a de-oxidised copper plate was a practical proposition and was done on the London Midland Region; it had, in fact, been carried out on tough pitch copper plate quite successfully.

In connection with welded stay heads, he appreciated the difficulties involved with the job and he thought the Author and the people at Gorton were to be congratulated on finding the secret of water cooling.

He mentioned that on steel stayed boilers over-size copper stays were occasionally fitted. In such cases the copper plate had been knocked back below the general level of plate, as a result of caulking of the steel stays, and the heads which were formed on the copper stays were flush with the copper plate. It was noted that such stay heads did not appear to waste and leakage did not occur. Welded stay heads also gave a flush finish with the plate, and he wondered whether the solution lay in this fact rather than in the welding of the stays.

He thought that the savings shown in Tables II, III and IV of the Paper overstated the case; for example, no allowance had been made for the longer prospective life of a new copper firebox as compared with the prospective life of a repaired firebox. Mention had been made that the fitting of two new half sides had increased the firebox life by 60 per cent., but in the tables such repairs were compared with the fitting of new fireboxes.

Had the cost of X-ray examination been included in the costs? He thought that for a half side costing about £60 in material and wages the cost of X-ray examination would be about £14; moreover it was extremely doubtful if an X-ray examination would reveal a crack in a copper weld which had subsequently been hot hammered.

On the operational side he thought one extremely important point had been missed. Very few copper welding jobs involved a single operator, the majority employed two or more. He emphasised the importance of team work between the operators, particularly when preheating and welding were carried out on the same job. Experience had shown that times could vary from one hour to two for the same length of weld, due entirely to lack of co-operation.

He said he agreed with the Author's views on piecework.

Mr. R. S. Hall (M.) asked, with regard to the flush welded firebox sides and water space stays, whether the Author would recommend a somewhat thicker inner firebox plate than normal. Mr. Hall visualised the plate as being rather thin in comparison with the diameter of the screwed stay, comparing the threaded portion with that of a bolt in a nut, the length of screwing in contact being generally about three fourths of the diameter (B.S.F.). With a copper stay of $\frac{7}{8}$ in. or even $\frac{15}{16}$ in. diameter the amount of thread in contact would be only the thickness of the firebox plate i.e. $\frac{7}{16}$ in. or $\frac{1}{2}$ in. or about half the diameter of the stay.

He asked where the films or negatives were placed when X-ray photographs were taken of the welds in the inner firebox plates. Normally the X-rays were focussed on the work, with the film pack placed behind, and behind that was placed a lead screen for protection purposes. With the water space stays in position it would be impossible to place the film immediately behind the inner plate and he wondered if the photographs were taken through two thicknesses of plate.

He asked if the Author would give some indication of the time for exposure for copper plates. With pressure vessels made of thick steel plate the exposure was usually of the order of 2 minutes per one inch thickness of plate.

Mr. T. F. B. Simpson (V.) said he believed that the Germans in 1916 started a process of copper welding stay heads and that they adopted a technique similar to that developed by the Author. He understood they also used a " drifted " stay as a means of overcoming the stay leakage problem.

Mr. E. D. Knights (V.) asked what the penetrameter sensitivity of detection was on the films described. He believed they were taken by passing the rays through the steel outer wrapper with the film placed on the fireside of the copper box. He thought the sensitivity would be rather low because even for the rays going through the copper box alone with the film in the water space, the sensitivity was of the order of one per cent.

Most of the copper welds he had examined had revealed many cracks and defects which were not normally accepted in ferrous welding. It was not possible to chip them out and reweld successfully with oxyacetylene, as with a steel weld, and they often finished up with cracks nearly as big as when they started.

In the case of welded stays, a rather deep pop mark was made $\frac{1}{4}$ in. deep and $\frac{3}{16}$ in. diameter. He asked if this had the same effect as caulking the plate round the stay, the stay being expanded on to the threads.

Regarding the test results for de-oxidised copper and silver phosphorus wire; were they on test plates? Had any results been tried on copper plate welded on one side with a backing strip exactly as is done in welding a copper box?

Mr. E. R. Durnford (M.) said they had heard some interesting remarks in the early part of the Paper with regard to the present methods of copper welding. They indicated firstly the intermittent welding, in about 6 in. lengths, followed by light hammering while the weld remained at a high temperature. The removable steel backing strip presumably was necessary to take the impact of the hammering. This method always seemed to him to lack finality. Secondly, the continuous weld using two welders and copper backing strip which became an integral part of the weld. Was he right in assuming that in this method no hammering was required, and that the copper backing strip was permanently attached before welding?

He asked the Author to indicate which in his opinion was the better method and why.

Mr. G. F. Parker (A.M.) asked whether a higher hydraulic test pressure than usual was used at Gorton after copper welding, or if radiography was considered sufficient.

With the small patches, which from the illustrations, appeared to be roughly semi-circular, he asked if there was any difficulty in maintaining the correct gap as welding proceeded.

He thought the meeting had overlooked the point made by Mr. Henstock regarding piecework that the actual welding amounted to only one third of the total time taken by a team doing a copper welding job. Much of the time was taken by preparation, and as the team, who presumably would pool their earnings, improved their manual dexterity, they could save time on that and still leave the actual welding speed unaltered. For this reason he thought it no more illogical to pay piecework for copper welding than for automatic and semi-automatic machines where the operators also have their speeds pre-determined.

MEETING IN GLASGOW 9th APRIL 1952

The Seventh Ordinary General Meeting of the Scottish Centre was held at St. Enoch Hotel, Glasgow on 9th April 1952, the Chair being taken by Mr. A. Hood.

The Minutes of the Meeting held on the 12th March 1952, were read, approved, and signed as correct.

The Chairman then introduced Mr. J. F. Harrison who read his Paper entitled " The Application of Welding to Locomotive Boiler Copper Fireboxes."

This was followed by a discussion.

DISCUSSION

Mr. A. Hood (Chairman) began his remarks by complimenting Mr. Harrison on delivering a most excellent and interesting Paper, and then raised a number of points:—

1. When seal welding stays, was the stay screwed as in normal practice and what was the depth of weld penetration?
2. In the plate preparation for seam welding, was the shaping done by hand or machine?
3. Were pneumatic hammers or hand hammers used for grain closing?

Mr. E. D. Trask (M.) raised the following questions:—

1. If a seal welded stay broke at a Motive Power Depot, this would raise difficulties of method of replacement; how was this to be carried out?
2. If seal welded stays were satisfactory, why had this practice not been adopted as standard on British Railways?

Mr. Murray (V.) asked:—

1. At what temperature range the hammering, to close the grain, took place?
2. When seal welding stays, using the water for cooling purposes as described, did any plate distortion take place?
3. Had only electrolytic copper filler rod been used for seal welding?

Mr. W. Thompson (A.M.) said:—

1. Was it possible to weld into a plate in position in a boiler, an insert, and if so, was the weld satisfactory or was it necessary to remove the plate so as to weld from both sides?
2. When inserting new half sides, could the stay holes be drilled before welding?

Mr. Ellis (A.M.) asked:—

1. What shape was the backing strip in section and, if a semi-circular patch was fitted, was a semi-circular backing strip used?
2. Had any fireboxes been produced which were all-welded?

Mr. G. T. Owen (A.M.) asked:—

1. If any allowance on the saving statements had been made for the value of scrap copper?
2. Could vertical seam welding be carried out?

Mr. J. Southern (A.M.) asked if it was necessary to pre-heat copper plates before welding and if it was necessary to weld both sides.

Mr. Ferril (V.) asked if it was the practice to weld fractures in door plates in position, or did the plate have to be removed?

Mr. Murray (V.) asked about the training of welders:—

1. How were they recruited?
2. What kind of initial training was given?
3. Were refresher courses considered necessary?

Mr. J. Sinclair (A.M.) asked whether the ' X ' stays illustrated on the slide showing a new half side being welded into position, were adjustable.

Mr. T. A. Crowe (M.) asked what was the reason for hammering; surely it tended to loosen the weld.

Mr. N. C. Dasgupta (G.) and Mr. Brown (V.) asked:—

What filler rod had been found most satisfactory for (*a*) seam welding of de-oxidised copper? (*b*) seam welding or arsenical copper?

Mr. Tweedie (V.) asked if the Author would describe the vacuum methods of weld testing referred to and also say what hydraulic and steam tests were carried out on the welded boilers.

Mr. Smith (M.) asked:—

1. Was it necessary to use a flux when welding with both the methods described?
2. Would the Author give an explanation of the use of Argon gas? What was its purpose?
3. Reference had been made to left hand welding; what was the difference between left and right hand welding?
4. Was pre-heating always carried out and what was the purpose?

AUTHOR'S REPLY

The Author wished to express his thanks to the President, Members and Visitors for their contributions to the discussion. The theoretical and practical questions raised at the various Centres amounted to more than 100 in number, and although some questions were repeated at successive meetings, it was felt that the grouping of replies under different sectional headings would save space, and it was hoped that the replies given in these circumstances would be accepted.

Savings

One point which caused a question at each Centre by *Messrs Bond, Hadfield, Henstock* and *Owen* was the apparent inequality of comparison of cost in Table III, wherein it was particularly stated that one half wrapper side welded in at a cost of £50 12s. 6d. was compared with the cost of a new firebox at £499 18s. 3d. On the Great Central Section of the former L.N.E.R. where water conditions were so bad, it had not been possible to make a satisfactory repair by riveting in half side plates, and the welding process had been developed with the object of saving a firebox which could not be repaired by any of the then known and accepted repair methods. If a half side was defective and all other plates were fit for a further extended period of service, then, and then only, would it have been correct to show a welded half side against a riveted half side, but such was not the case in the actual boilers (including all boilers repaired by welding) which were referred to in Table III.

On the general question of savings, their compilation and scope, raised by *Messrs Hinds, Johnson, Foster* and *Owen*, no account had been taken of eventual savings due to increased engine availability, nor had any additions been made to cover overheads (including the Welding Expert and the X-ray Photographer), as it was felt that overheads would increase the savings to phenomenal figures, but scrap copper was included.

Equipment

Considerable discussion developed around the two methods of seam welding referred to in the Paper as (1) the steel backing strip method, and (2) the included copper backing strip method. *Messrs Cook, Crane, Crowe, Hinds, Hatchell, Henstock, Taylor, Durnford, Ellis* and *Southern* raised points in connection with each method. The reason why the former method was employed on the Great Central Section was to ensure that the welded seam had the same strength as the new parent plate. If this condition was not desired, then there was no reason why the latter method, using an electrolytic copper filler rod with a de-oxidising flux and a permanent copper backing strip, should not be used, although in bad water districts the backing strip would collect scale freely. The backing strip in either case was shaped as shown in Fig. 20.

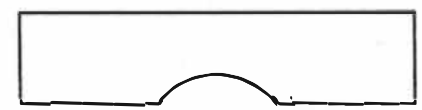

FIG. 20

This generally raised points on the composition of the Cu.Si. filler rod and the necessity for its use. *Messrs Cook, Burt, Owen, Brown, Dasgupta* and *Smith* referred to this in some detail. It can be said that the composition of the filler had varied throughout the years and that at present the most suitable de-oxidising filler rod was one with not less than .25 per cent. Silicon.

For seam welding, reference had been made to a gap of $\frac{3}{16}$ in. per foot run. This point was questioned by *Messrs Cocks, Compton* and *Smith*. In setting the two plates for welding a seam of, say, 4 ft. in length, the two plates were positioned with a gap at one end of $\frac{3}{16}$ in., and at the other end of $\frac{3}{16}$ in. + four times $\frac{3}{16}$ in. = $\frac{15}{16}$ in.

Failures

Messrs Hinds and *Foster* made reference to the number of failures; as Mr. Hinds stated, if the failures were analysed, they were found to be remarkably low, and, in fact, the insert patch failures (3 sided welds) were probably as difficult to avoid as any form of seam welding, but, in fact, only occurred during the earlier repair periods when the technique was not so good as in later years.

The repair of tubeplate bridges by welding was generally agreed by *Messrs Cook, Henstock* and *Durham* as being a repair which was not entirely satisfactory, although Mr. Cook maintained that a mechanical repair by bushing was equally unsatisfactory. This, however, had not been the Author's experience.

Messrs Hinds, Gladwin, Foster, Parker, Thomson and *Ferril* referred to the slides illustrating semi-circular patches, and asked what were the governing factors in deciding whether to patch, build up or fit a new half side. The semi-circular patch should only be fitted when the adjacent plate was in good condition (reasonably thick and free from stay hole grooving) and when the length of the circular seam and the number of stays to be renewed was not more than 70 per cent. of length of a seam and total stays to be renewed. No difficulty had been experienced in preventing the retention of the weld metal within the welding V by means of a steel backing strip.

A short description of the method used and staff employed in welding operations would answer the questions raised by *Messrs Durham, Foster, Brown, Southern* and *Smith*.

The team consisted of three men, all skilled welders, one of whom acted as the pre-heater. The second man carried out the actual welding operation using the filler rod, and the third man ensured supply of oxygen acetylene, filler rods, adjusted water level for seal stay welding and took over the hammering operation, including the setting of the " dolly " for hammering stays. All operators changed positions during the day so as to ensure the minimum of heat fatigue; each member of the team changed position with one of his opposite numbers once every hour or period of welding.

Training, Testing, Supervision of Welders

Messrs Henstock, Parker, Foster, Walton and *Tweedie* gave divergent views of the method of payment to be made to copper welders. It was, in the Author's opinion, essential to ensure that the actual welding operation was carried out at the correct speed, neither faster nor slower, and as only two members of the team, the pre-heater and welder, controlled the gang payment, and were prohibited from going too fast or too slow, then it followed that piecework or payment by results (in this case " results " would mean length of seam or number of stays per hour), could not be logical.

Mr. Bond referred to the qualifications required from a welder of copper fireboxes. The first requirement should be that he had *acquired the proper technique* and put into practice lessons learned from interpretation of radiographs. If, in addition, he had boiler-making experience all the better, but it was not vital.

Messrs Dick and *Murray* asked various questions covering the training of operators and the testing of their initial work. The reply given to Mr. Bond's similar question would answer the point covering initial qualifications. Once the welder had acquired a rough idea of the problem to be mastered, he could be given test pieces to work on. When he was able to produce a seam weld that would bend through 180° when cold, he may be said to have acquired reasonable proficiency. Cold bend testing was not, of course, resorted to except on test pieces. The Author had no knowledge of failure of the operator during or after training.

Radiography

Radiography drew forth a number of most interesting questions. *Messrs Turner, Wise, Foster, Hall, Knights, Doran, Maddison* and *Smith* raised various points. It was agreed that radiographs did not indicate easily inter-granular cracks of copper cuprous-oxide eutectic, but it was felt that they did show clearly the various simple, but serious, faults which could occur from time to time even when the welding had been carried out by the most experienced operator. Radiography was not intended to be used as a check on every length of seam or individual stay welded, but only as a routine check to ensure that the operators were keeping themselves up to pitch. No other alternative was available for below surface examination, except destructive testing. The cost of radiographing two seam welds was approximately 30/- in wages and materials.

The penetrameter sensitivity of the plate was .005 to .025 on $\frac{9}{16}$ in. copper plate, a maximum of 99 per cent. definition.

The exposure time was 12 minutes 28 in. focal distance 145 kV at 145,000 volts 20 mA, the negative being placed inside the firebox, the steel casing acting as a filter.

All radiographs of seal welded stays were taken after the head had been riveted on the outside steel wrapper plate.

Messrs Turner and *Spencer* asked what effect welding had upon the parent metal. After tests had been carried out it was found that the adjacent parent metal was unaffected and that seal welded stays could be drilled out, re-tapped and re-fitted without any difficulty.

Messrs Compton, Turner, Dasgupta and *Smith* asked if all copper fireboxes on British Railways were now made from de-oxidised copper plate. The specification to which copper firebox plates were ordered was as follows:—

B. R. Specification No. 301

Quality—To comply with conditions laid down in the current issue of British Standards Report 24, Part 5, Specification 11. Manufactured from phosphorus de-oxidised arsenical Copper in accordance with the current issue of British Standards Specification 1174.

After seal or seam welding with a Cu. Silver filler rod it was essential to close the grain of the welded metal. This was usually done with a light pneumatic hammer, not with a hand hammer which would take too long; the use of electrolytic copper filler rod did not call for hammering after welding, and it should be clearly understood that the hammering was in no way a riveting process. *Messrs Cook, McHugh, Hood* and *Evans* raised points of interest on this aspect.

Seal Welding

With regard to the various questions asked by *Messrs Bond, Burt, Johnson, Durham, Taylor, Cocks, Foster, Simpson, Hood, Henstock, Maddison, Rose, Murray, Ellis, Trask* and *Smith* covering the seal welding of stays, methods adopted, and methods tried with and without success; it was suggested that the various questions were answered below.

It should be borne in mind that water conditions largely governed stay leakage. It may be true to say that, where water conditions were good and the tendency to leak consequently reduced during the cooling down process, the effect of burning off the head of the stay was not so serious as in bad water conditions, but, undoubtedly, in bad water districts leakage could and did take place at a very early stage in the stay life; the subsequent re-hammering of the stay heads did not and could not be expected to seal the gap that had already been formed between the stay and the tapped hole in the plate; permanent deformation set in and all subsequent " hammering up " operations tended only to close the stay head to the plate. If, however, the stay at the firebox side could be welded to the plate and if subsequent plastic deformation did not break up the weld, then the stay was effectively sealed to all leakages. The Author was particularly interested to have *Mr. Foster's* remarks that copper stays riveted flush with the firebox plate did not leak. Originally, it was intended to fit the screwed stay in such a way that $\frac{1}{16}$ in. or more of stay protruded into the firebox and then weld this protrusion to the side plate. Stays welded in that manner stood proud of the plate, but it was not possible in the welding operation to control the fluid copper sufficiently accurately so that the centre of the protrusion was coincident with the centre line of the stay, nor was there sufficient penetration of the side plate to ensure an effective seal.

After some time experimenting, it was finally found that the best results were achieved with a stay fitted flush with the side plate having a slight recess prepared around the stay head to control the fluid copper. This method gave good penetration up to two to three threads, and, of course, produced a final firebox plate which was flat.

With the flat plate, it was necessary to ensure that the centre of the stay was visible to the Shed and to the Mechanical and Electrical Engineer's Boiler Inspector when carrying out hammer testing, and thus was evolved the method referred to in the Paper of lightly " popping " the stay line centres vertically and horizontally so as to mark off the centres of the stays for final punching; this punching in no way acted as " drifting." It would be difficult to use a boiler shop template for the marking off, owing to the number of riveted stays in position, which would tend to distort the "lie" of the template. Attempts had been made to seal weld stays with the centre punch in position before welding, but this had not been successful, as during the welding operation, the copper head all became fluid, thus flooding the punched hole. No difficulties had been experienced by boiler inspectors in testing seal welded stays, and in view of this it was not thought necessary to produce a seal welded stay with a head.

Some thought had been given to the possibility of welding stays into plates without the necessity of screwing the stay and tapping the plate, but this had so far not appeared to be very practicable owing to the difficulty in obtaining sufficient penetration to ensure the necessary weld strength.

Experiments had been carried out by welding drifted stays, but these had proved no more successful than had some experiments which had been carried out at Gorton in the early 1930's with the German design of drifted stay unriveted.

The seal welding of stays had not been applied to portions of the firebox above the brick arch, but it was not visualised that if such stays were welded they would give any different life from those in the fire area.

Messrs Jefferson, Stuart, Trask and *Owen* raised the question of the replacement of a welded stay if such a stay fractured; there was no difficulty in replacing a broken welded stay with an ordinary steam tight stay. One could not with present equipment fit a stay horizontally and then weld to the firebox inner plate, although this was thought to be a probable line of development with the "Aircomatic " process.

The life of seal welded stay fireboxes could not yet be determined in comparision with the normal riveted stay fireboxes, as no seal welded

stay fireboxes had so far needed any stays replacing, although what few were in service had already exceeded the normal shop to shop mileage by 100 per cent.

The Author particularly wished to thank *Mr. T. H. Turner* for his remarks and copy of bibliography on the subject matter. The annular flame welder had been tried at Gorton as well as the carbon arc process, but without any success. In the carbon arc process the heat created made the copper so fluid that no control could be exercised.

Dr. Haydon raised the question of nitric oxide poisoning and metal fume fever. From experience extending over 5 to 7 years, no cases had occurred of either metal fume fever or nitric oxide poisoning, nor had there been any cases of other respiratory diseases. Particular care was taken to provide operators with respirators, and if the space in which they were working was confined, cold fresh air was blown into the space by means of a fan.

Mr. Burt's clear description of the Argon Arc Inert Gas Shielded welded process known as the " Aircomatic " process was most interesting and was the process referred to by the Author under "Better Welding Methods." The process used an arc shielded by an inert gas. The electrode, in this case the welding wire, was consumable. The wire was fed to the holder through a hollow cable, which also conveyed the Argon gas to the welding area. The filler wire was fed to the holder by a feed motor at a constant speed, the arc length remaining constant consequent upon an electrical phenomena which was inherent in the process. If the welder drew the electrode away from the work, thereby lenthening the arc, the burn-off rate was reduced, the arc subsequently becoming shorter; if the welder on the contrary brought the wire closer to the work, the reverse took place. The diameter of the filler wire was approximately $\frac{1}{16}$ in. and could be fed at speeds varying from 150 to 400 inches per minute. It was essential to use a high current density for two reasons, firstly, the metal transfer was of a small spray type and left the end of the wire with sufficient velocity to permit *welding in all positions*, and secondly, it was only at the high current densities that the self-adjusting arc phenomena took effect.

The above process produced welds at a speed of between two to five times as fast as Argon arc welding, and its main advantages were that fillet welds could be made in difficult positions as also could the process of building up.

The cost of the equipment was not known, but it should not exceed £800-£1,000.

Efficiency in a locomotive may be termed " Work done per annum divided by cost per annum."

Work done should be train/ton miles run.

Cost per annum must include Interest on Capital, Fuel Costs, Staff Costs and Maintenance Costs.

The Steam Engine was cheaper in the first case than either Electric, Diesel Electric, Diesel Mechanical or Gas Turbine.

Fuel costs per train/ton mile were cheaper for steam than any of the other forms of motive power.

Staff costs could only be cheaper for one form of motive power than another if availability was increased, such as was the case of diesel shunting engines.

The maintenance costs of a steam locomotive could be higher than other forms of motive power, due principally to the additional boiler cost. Therefore, if these boiler costs could be appreciably reduced by producing non-leak fireboxes, the cost of maintenance of the steam locomotive would become not much greater than maintenance costs of other forms of motive power; certainly those higher costs would not be sufficient to outweigh higher interest charges on original capital required to build the other forms of motive power.

Summing up the various replies in detail, it could be said that there were two distinct forms of oxy-acetylene welding of copper now in use on British Railways, as detailed above. Either process gave satisfactory results in accordance with the standards required. It was thought, with some confidence, that the " Aircomatic " process would cheapen repair costs considerably and enable new and repaired fireboxes to have their lives extended.

MEETING IN LONDON 16th APRIL 1952

The Eighth Ordinary General Meeting of the Session 1951-52 was held at the Institution of Mechanical Engineers, Storey's Gate, London, on Wednesday, 16th April 1952, at 5.30 p.m., Mr. Julian S. Tritton occupying the Chair.

The Minutes of the previous meeting were read by the Secretary, and were confirmed and signed as correct.

The following applicants for membership were duly elected:—

MEMBER

BAKER, ERIC HERBERT, Assistant Divisional Motive Power Superintendent, British Railways, L.M. Region, Derby.

ASSOCIATE MEMBERS

BURNETT, JOHN McALLISTER, Inspecting Engineer, Messrs Rendel, Palmer & Tritton, 125 Victoria Street, S.W1.

CHAN, PENG KHUEN, Mechanical Engineer, Chief Mechanical Engineer's Office, Malayan Railway, Sentul Works, Kuala Lumpur.

DODRIDGE, DENIS EDWIN, Technical Assistant, Electrical Engineering New Works & Development Section, Railway Executive, King's Cross London, N.1.

JOLLEY, LESLIE CHARLES, Technical Representative in India, Pakistan and Ceylon, British Timken Ltd.

ASSOCIATE

SMITH, JAMES HOPEWELL, Managing Director, Hulburd Patents Ltd., London, W.3.

GRADUATES

GHOSH, RAJAT KUMER, Recently a trainee at Vulcan Foundry Ltd., Newton-le-Willows, since returned to India.

IORNS, JOHN VICTOR, Draughtsman Grade II, East African Railways and Harbours, Nairobi.

KOCHHAR, ROSHAN LAL, Engineering Apprentice, Tata Locomotive and Engineering Co. Ltd., Tatanagar, India.

ROE, ALFRED KENNETH, Draughtsman (Trainee) Locomotive Drawing Office, British Railways, Derby.

WEBB, DEREK ANTHONY, Motive Power Shed Master, British Railways, Western Region, Oswestry.

TRANSFERS, ASSOCIATE MEMBERS TO MEMBERS

DE MELLOW, HARRY NOEL HUBERT, Deputy Chief Mechanical Engineer, Jodhpur Railway.

MADDEN, ALFRED HOWARD, Divisional Motive Power Superintendent, British Railways, L.M. Region, Hunts Bank, Manchester.

OWEN, GEOFFREY THOROLD, General Manager, North British Locomotive Co. Ltd., Glasgow.

The President then introduced Lieut.-Colonel L. F. R. Fell, D.S.O., O.B.E., M.I.Mech.E., F.R.Ae.S., Member, who read his Paper entitled " The Fell Diesel Mechanical Locomotive."

The paper was afterwards discussed and, on the motion of the President, a vote of thanks was accorded to the Author.

THE FELL DIESEL MECHANICAL LOCOMOTIVE†

Lt.-Col. L. F. R. FELL, D.S.O., O.B.E., M.I.Mech.E., F.R.Ae.S. *(Member)**

Paper read before the Institution in London on 16th April 1952

Repeated in:—

Leeds 24th April 1952 (*page* 262)
Newcastle-on-Tyne 29th April 1952 (*page* 265)
Derby 14th May 1952 (*page* 268)

PAPER No. 512

The advantages of the diesel engine driven locomotive have so frequently and so ably been set forth on previous occasions that in this lecture it will suffice to refer only to the diesel locomotives' disadvantages as compared with the steam locomotive. These are as follows:—

1. High first cost per unit of weight.
2. Low draw bar horse power per unit of weight.
   These two disadvantages can be resolved into a third, namely,
3. High first cost per draw bar horse power.

The protagonists of diesel locomotives are given to covering up the deficiency referred to under (2) by quoting spectacular figures for maximum tractive effort which are obtainable by the use of various forms of torque multipliers. Steam locomotive men are sometimes misled into believing that these high maximum tractive effort figures mean that the diesel locomotives in question are the equivalent in

† Author awarded the Frederick Harvey Trevithick Award (value £30) for this Paper.

* Director, Fell Develo[illegible]nts Limited.