Discussion.

The President. The PRESIDENT was sure the members would join with him in according to the Author, an esteemed member of the Council, a hearty vote of thanks for the facts he had so carefully placed before the Institution. Although they occupied but a comparatively small space, those facts must be the result of a large amount of research, occupying much time.

The Author. The AUTHOR remarked he had little to add to the Paper, which, he thought, set forth fairly fully the reason for bringing the matter before the Institution. It was one of the most important questions in railway working, particularly in view of the large amount of work which modern locomotives had to perform in comparison with engines of earlier days, when pressures of 90 lbs. to 100 lbs. per square inch had been used. He had ordered the experiments to be made in consequence of the peculiar behaviour of a number of stays of metallic alloys, which the locomotive department of the London and North Western Railway had been asked to try. Although the alloys in question, when cold, would stand every mechanical test applied to them without failure, when they were used in fire-boxes they began to cause serious trouble. He had gone cautiously to work in the matter; but, as was mentioned in the Paper, after putting some of the bronze stays in a boiler, he had quickly been convinced that the best thing he could do was to take out every stay, because the stay-heads had begun to drop off whenever the engine worked hard—though shunting seemed to be performed without any trouble. He had become uneasy about the matter, and had thought it advisable to investigate the whole question of fire-box stays, in order to see if any material would answer better than the copper which had been employed for the purpose for so many years. The results of the tests showed that the best joints were obtained when the material of the stay was softer than that of the fire-box. To enable the members to see the results on a large scale, he had caused lantern-slides of the photographs in the Paper to be prepared, and he would ask Mr. Tipler, who had had charge of the experiments, to explain these slides as they were exhibited. When photographs of the mixtures of aluminium and copper were shown, it would be readily seen why, at a certain temperature, the strength of the material seemed to fail suddenly. The actual specimens

of the materials tested were exhibited on the table. His thanks The Author. were due to Professor Unwin for having kindly exhibited his apparatus for testing hardness.

Mr. F. C. TIPLER then explained the photographs illustrating Mr. Tipler. the Paper, slides of which were projected on the screen.

Mr. JOHN A. F. ASPINALL remarked that the Paper dealt with a Mr. Aspinall. subject of immense importance at the present time in locomotive work. Early in the Paper it was mentioned how frequently stays had to be renewed, and he thought that pointed to the desirability of getting rid of the stay altogether, if possible. Engineers ought to look forward to a time when they would get rid of the rectangular fire-box and adopt something circular. So far as a locomotive as a whole was concerned, there could be no doubt that the only part of it which gave trouble was the boiler. As a machine and as a vehicle it gave no trouble whatever; it went on working from year to year, requiring only a little occasional repair. But the boilers were a source of everlasting trouble; and trouble in the boiler nearly always meant trouble in the fire-box. Therefore, if locomotive engineers could successfully devise some form of circular fire-box, it would prove to be one of the most important achievements of the time. Of course there were serious difficulties in getting, on a locomotive, a reasonably large fire-box having a corrugated flue. The results of the experiments described in the Paper tended to confirm results obtained by him some years ago at Horwich. His friend Mr. Hoy had made similar researches more recently, and the results also supported the Author's statements. He had no doubt the Author's opinion that the material used for the stay should be softer than that of the plate, really went to the root of the matter; one other point might be added, namely, that the plate should be reasonably hard. For many years a view had been held with which he entirely concurred, namely, that there should be a small proportion of arsenic in the copper, so as to give a harder plate. That enabled a harder stay to be used, having a longer life. Care must be taken not to have too hard a plate, otherwise it would crack against the flanges, and also between the tube-holes; then the remedy would be worse than the disease. With regard to steel stays, some of which the Author had exhibited, at one time he had used a large number, but they had been found to be not altogether satisfactory. There had been the same kind of trouble with breakage as the Author appeared to have experienced. While steel seemed to answer in engines worked at low speeds, such as were required for local traffic, it did not seem to answer well for other

Mr. Aspinall. classes of engine. There could be no doubt that in some express locomotives the stays on the side of the fire-box which were near to the expansion angle-bar broke much more readily than those in other parts of the box. The fact was, that in the locomotive fire-box, with copper plate inside and steel plate outside, there were what might be termed two "drum-heads" tightly stretched and tied together by the copper stays. If on the outside of that there were an angle-bar which, though free to move, did so with a certain amount of friction, it could be imagined that if the engine lurched from side to side, the friction was increased, and the angle-bar pulled out the side plate. That additional pull would be quite sufficient to break a stay which had some little flaw in it. Undoubtedly, for that and other reasons a larger percentage of stays were broken upon express engines than upon engines working easy-going trains.

Mr. Dobson. Mr. J. M. DOBSON remarked that he had read the Paper with much interest, and considered that the Institution was greatly indebted to the Author for the clear manner in which he had dealt with the subject. Personally he was very glad the question had been opened up, as it was one which many engineers had been considering for a long time. The Paper dealt with three causes of failure of stays—wastage of heads, leakage, and breakage; and stated that the breakages were chiefly due to the expansion and contraction of the copper box. Of that there was no doubt; hence the great importance of obtaining the best and most suitable metal to allow the stays to bend in the manner required by such expansion. On the other hand, apart from the question of the metal of which the side stays are made, it was more than probable that they might also become leaky if proper provision were not made for the lifting of the roof of the copper box when the side plates and tube-plate were expanded by heat. If the roof could not rise, the flexure of the copper plates would naturally follow the top flange of the tube-plate—where the thickness was reduced—and the line of the top rows of stays in the side plates, enlarging the holes and causing leakage. The order given to the foremen that boilers were to be frequently and carefully washed out, was of the utmost importance, and insufficient attention to it was the cause of many of the troubles which occurred. Neglect of that procedure not only caused the stays in the lower portion of the box to become coated with scale, to become over-heated and to break as stated, but side stays in other positions were known to have failed for the same reason, and it had even rendered useless the most carefully-designed expansion-arrangement. He alluded to

the question because within the past year his firm had had to deal with a case which proved its importance. In a number of engines built by a leading firm, and fitted with the Belpaire fire-box, expansion-links had been provided of a design which had been found to answer perfectly on other lines. The tube-plates in all those engines had had to be replaced, because they had utterly failed. Such had been the impression created by those failures that Belpaire boxes had been strongly reported against. In consequence, he had communicated with all the locomotive superintendents on the French lines and also with the locomotive superintendent of the Belgian State Railways, and their testimony, without exception, was in favour of the very fire-box and expansion-links—where they had been used—that were supposed to have

Fig. 46.

caused the whole of the trouble. Why should that box and those stays answer on the French and the Belgian lines, and on many lines in this country, and yet fail elsewhere? He thought it would be apparent from *Fig. 46* that the cause was owing to the expansion-arrangement failing to work through the scale accumulated on account of insufficient washing. One of the advantages of the Belpaire box was that, as the top of the copper box was lifted by expansion of the copper tube-plate, if the roof stays were all rigid the expansion was transmitted to the flexible iron or steel shell; and in order to get over the difficulty of the want of flexibility in the portion of the roof which came nearer to the boiler-barrel, one, two, and sometimes three rows of expansion-links, as shown by the diagram, were introduced. In the engines referred to, those links had been attached to a strong T-bar

Mr. Dobson, riveted to the top shell, and if by any chance those links became jammed, which would result from a very small amount of incrustation, then what should be flexible became rigid, and thus what should be an additional source of safety was really a source of danger. An inquiry had been held, and it had been decided that the failure arose from the expansion-arrangements not having, from some cause or other, worked properly. That should teach engineers, in designing expansion-arrangements, to avoid anything likely to become fixed. A great many of the expansion-arrangements at present existing on engines, neat as they were in design, were likely to become a source of trouble if the scale were not properly removed by washing, or if they became jammed from some other cause. Mr. Hawkshaw and he were now adopting the expansion-arrangement shown in *Fig. 47*, by which the T-bar was got rid of,

Fig. 47.

and latitude was obtained. That arrangement had been found to answer perfectly on other lines; but even it might be choked if scale were allowed to accumulate. He referred to those failures of tube-plates with no desire to find fault, because there were so many circumstances and local conditions to be taken into account—such as the quality of the coal used, of the wood, and of the water—that the locomotive superintendent had to be ever on the alert, so that when the evil was traced to its true source remedies might at once be provided. Some time ago he had had an opportunity of carefully examining a copper fire-box completely coated with scale. It had been taken out of a 14-inch cylinder engine, which had been running at the Poynton and Worth colliery for 12 years. That copper fire-box had been attached by direct roof-stays to a semi-circular iron

box, without any provision being made for expansion, a practice Mr. Dobson. which experience had proved to be unwise. The box had shown very clearly how the tube-plate had expanded, there being about $\frac{3}{8}$ inch difference between the level of the front and back plates; and although none of the roof- or side-stays had been broken, they had been bent considerably. That box was only a small one, 2 feet 10 $\frac{1}{2}$ inches long by 2 feet wide. Undoubtedly, in a large box with stays of a similar design, the danger would be considerably increased, and would result in the cracking of the tube-plate, or breakage of the stays. During the past week he had inspected another copper box, taken out of a six-wheel-coupled tank-engine having 16-inch cylinders. It was coated to such a degree that the stays which were attached to the girders over the whole roof were bedded in one complete mass of scale, so that nothing could be moved. The Author stated that in the forty engines of the "Diamond Jubilee" class one stay for every 844 miles was replaced; while in the case of the ten locomotives of the "Alfred the Great" class each engine ran 17,000 to 43,000 miles without it being necessary to replace any stays. Before it would be possible to arrive at a comparison between those two classes of engines it would be necessary that the ten of the "Alfred the Great" class should have run 1,405,516 miles, whereas they had only accomplished 277,800 miles. On the other hand, while the copper-zinc alloy, with 40 per cent. of zinc, had given a very unsatisfactory result, the copper-zinc stays with 9 per cent. of the latter metal, had given a highly satisfactory result, as the Author admitted; and would compare not only with the copper stays of the seven six-wheel-coupled engines doing precisely similar work, but also with the stays of the forty engines of the "Diamond Jubilee" class; thus:—

	"Diamond Jubilee" Class (40). Pressure 200 Lbs. per Square Inch. Copper Stays.	Six-wheel-coupled Coal Engine. Pressure 150 Lbs. per Square Inch. Copper-Zinc Stays (9 per Cent. Zinc).	Six-wheel-coupled Coal Engines (7). Pressure 150 Lbs. per Square Inch. Copper Stays.
Average number of miles run by each engine .	140,552	284,978	Not given.
Average number of stays replaced in each engine	166.5	51	Not given.
Frequency of renewal .	1 per 844 miles	1 per 5,588 miles	1 per 1,805 miles.
Average time of running	4 $\frac{1}{2}$ years	10 years	10 years.
Number of broken stays in each engine . . .	None recorded	14	Not given.

Mr. Dobson. Taking this comparison into consideration, and seeing that the copper-zinc alloy (9 per cent. of zinc) had given such a good result, he thought it would be of great value if the Author would, if possible, give the information necessary to complete the comparison between the seven engines fitted with copper stays and the one engine with copper-zinc (9 per cent. zinc) which did precisely similar work; and also if he would say why he had not used that kind of stay, seeing that even in the case of the engine of the "Diamond Jubilee" class, while one copper stay failed in every 844 miles, the copper-zinc alloy (9 per cent. zinc) gave $6\frac{1}{2}$ times the life, only one stay failing in 5,588 miles. Moreover, although the coal engine was only worked at 150 lbs. per square inch, it had been working for 10 years, while the "Diamond Jubilee" class of engine had only run for $4\frac{1}{2}$ years; and although, during the 10 years, 14 stays had been broken in the coal engine, those replaced in the "Diamond Jubilee" engines had been for wastage of heads and leakage, and it would be interesting to know the percentage replaced on account of leakage. With regard to copper-manganese stays, the report from the Hungarian State Railways to the Railway Congress in Brussels in 1900, as also from the Northern Railway of France, was that they had given great satisfaction. On the Northern Railway of France copper-manganese stays had been found necessary, owing to the failure of copper stays in large boxes. The Southern Company of France had decided to use copper-manganese for their fast express engines which they had built in 1900. Of course that company had not yet had those engines running for a sufficiently long time to give a fair comparison; but copper-manganese stays had been used on the Hungarian State Railways since 1890, and it appeared to be of great importance, therefore, that the value of these stays should also be tested in England. In the Author's diagrams, *Figs. 15 and 15a*, the results showing for materials Nos. 1 to 6 the average tensile strength, and also the average elongations and contractions of areas at the different temperatures, were striking; but it must be remembered that the copper-zinc alloy (9 per cent. zinc) did not appear in the diagrams, for the reason given by the Author. Copper-zinc (40 per cent. zinc) was shown, but bearing in mind that the melting-point of zinc was 736° F., the result in regard to that material was not surprising. If the copper-zinc (9 per cent. of zinc) had been tested, no doubt the result would have been very different. The most satisfactory results of the tests shown by *Figs. 15 and 15a* were from mild steel. With regard to the riveting of stays, the forma-

tion of a large head certainly affected the stay by increasing its thickness in the centre. The Author, in his conclusions, stated that it was necessary that the stays should be softer than the plates. He could understand why they should be as soft, but not softer; and if a very soft stay were used, he thought there would be a risk of the two plates coming together. He had had tests made more or less on the basis of the Author's, and the result had been that the plates had come together nearly $\frac{1}{32}$ inch, and the heads had had to be reduced. If the stays were made soft he did not see how the difficulty was to be met. He would be glad if the Author would say how he formed the heads, whether by hand hammers or by pneumatic hammers, and he would also be glad if, with his great experience, the Author would state what he considered should be the proportion of arsenic in the plates compared with that in the stays. In the analysis of the copper rod (No. 1, p. 107), where the ultimate tensile strength was 14·32 tons per square inch the amount of arsenic was given as 0·20 per cent., while in the analysis of the special copper rod (No. 6, p. 112), where the ultimate strength was 17·48 tons per square inch the arsenic was given as 0·01 per cent.; perhaps this was due to a clerical error. Again, the copper which gave what the Author called the "excellent joint," showed 0·55 per cent. arsenic for the plate and 0·34 per cent. for the stay. His firm specified 0·25 per cent. to 0·40 per cent. of arsenic for both plates and stays, but of course the tensile strength of the metal when cold was greatly affected by the method of treatment.

Professor W. C. UNWIN remarked that the Paper was extremely interesting, and was a typical account of a careful inductive investigation. The experiments were ingenious and conclusive. He had thought it might be useful to place on the table the apparatus with which the indentation-tests were made. He had concluded some time ago that, for certain purposes, it was of importance to determine the hardness of a material, quite independently of the qualities ordinarily tested. An indentation-test had been used for 50 years or more in testing hardness, but all the early indentation-tests had been made with a diamond-pointed tool, which had been caused to make an indentation by the blow of a falling weight. That had appeared to him to be a somewhat inconvenient mode of testing. In the first place, a diamond-pointed tool was difficult to keep in an exact form, and the measurements were not easy. Moreover, there was no graduation in the test if a falling weight were used. He had therefore contrived the little machine exhibited, in which the indentation was made in the ordinary statical testing-machine. The

Professor
Unwin.

Professor Unwin. indenting-tool was simply a piece of steel of square cross-section, the four indenting edges of which could be used successively. The angle of the edge being a right angle, it was easy to grind it true; and as it was of very simple form it could be made excessively hard. The indenting-tool came down on top of a specimen $\frac{1}{2}$ inch by $\frac{1}{2}$ inch by 2 inches, and a vernier was provided for reading the depth of indentation.

Mr. Pilkington. Mr. WOODFORD PILKINGTON remarked that he would have been glad if the Author had tried some other stays, particularly some aluminium-copper alloys having aluminium as the base, as he was much interested in aluminium alloys. He had succeeded in obtaining specimens of aluminium as hard as Bessemer steel, and had submitted them to the War Office as "aluminium-steel"; and he hoped to increase the hardness until it approached that of the diamond.

Mr. Tritton. Mr. S. B. TRITTON remarked, in reference to the Author's statement that the effect of riveting copper alloys in copper plates had been to expand the hole in the plate at the base, that it would be interesting if any members who had made experiments on nutted stays with solid heads would give the results. He and his colleagues had made experiments with several fire-box stays with solid heads, but mechanical difficulties, such as the difficulty of knowing whether the thread was really tight in the plate, or whether the stay was bearing on the head, placed obstacles in the way of carrying the experiments forward. Both Lloyd's and the Board of Trade, however, offered a certain premium in their rules for stays fitted with nuts, that was, their constant for nutted stays was a more favourable one than that for stays merely screwed in and riveted over. It might be said that nutted stays in the fire-box of a locomotive would not answer, as they would burn away at once: but in many cases the roof-stays were nutted. It was true they were made of a different material, but the subject was worthy of investigation. All the experiments which had been made to show the breaking-down point at which screwed stays in fire-boxes failed, proved that a good head of some kind was an important element in the strength of the stay; and if a solid head of some form could be relied on, and could be mechanically effective, the subject might well be pursued further. Some of the diagrams in the Paper showed that the breaking-down point seemed to occur where the effect of riveting was most noticeable. In the case of many of the alloys, especially the harder alloys, the thread was much broken, and a predisposition existed for it to waste away under the action of the fire. In the stays of the softer alloys and copper that had not so much effect. It

would be interesting to know whether the Author cupped his stay Mr. Tritton. with a cupping-tool, or whether the stays were knocked down under the hammer. Investigation had shown that there was a considerable difference in the effect on the stay when so treated.

Sir FREDERICK BRAMWELL, Bart, Past-President, remarked that many years ago an explosion had occurred in the boiler of H.M.S. "Thunderer," and that explosion had taken place where the front of the boiler and the flat surface had been stayed. The stays had been merely riveted, there being no nuts. The coroner's assessor, Mr. Fletcher, and himself, in the course of the enquiry had had made a mere flat box with sides 4 feet or 5 feet square and 4 inches or 5 inches apart, stayed together with stays such as had been in the real boiler, at about 6 inches or 8 inches apart. By hydraulic pressure that box had been tested to destruction, and the plate between the stays had been found to be bulged outward, so that the hole in the plate had become conical on the inside to such an extent as to entirely release the hold of all but one or two of the threads, which had then given way. The stays of some corresponding boilers under inspection and investigation had been provided with nuts; and in these boilers the fact of the hole in the plate becoming conical and thus releasing the threads of the stay, had not affected the part of the stay which passed through the nut.

Mr. DRUITT HALPIN, referring to Mr. Tritton's remark as to Mr. Halpin. Lloyd's and the Board-of-Trade rules allowing extra value for stays which were nutted, observed that this applied only to stays used in combustion-chambers and places of that kind, where the temperature was relatively moderate; and the circumstances were not parallel with those in the question under discussion, where temperatures running up to 2,500° F. and 3,000° F. were used. To put at the sides of a locomotive fire-box nuts of the kind used successfully in marine work under other circumstances would be a different matter.

Sir FREDERICK BRAMWELL explained that he did not advocate the use of nuts in a locomotive fire-box, but had simply endeavoured to show how, in the absence of a nut, it was possible for the hole to be opened so as to release the threads of the stay.

The PRESIDENT remarked he was not able to add any information with regard to locomotive fire-box stays, inasmuch as he had had no experience with them; but he would mention an experience he had had with studs of phosphor-bronze which had not been subjected to heat. These studs had been used for attaching the gun-metal face of a large waterworks valve to the cast-iron

The President. body of the valve itself. They had been screwed into the face of the valve, passing through the cast-iron flange of the body of the valve, about 2 inches in thickness, and being then screwed up with nuts. After the bolts had been in for some little time they had been put into a tunnel, and subsequently several of them had been found to be broken in two. The valve had never been in use, and the door had not been put into position. It had been supposed that that might be due to a difference in contraction between the phosphor-bronze and the cast-iron. The studs had then been replaced by manganese-bronze studs. Again the same thing had happened, but to a less number of studs; and it had been found on examination of the bronze of which the studs were made that the mixture did not appear to be evenly distributed. But it was difficult to understand why they had failed, seeing that they had been doing no work and that the valve had never been in use: even when it was in use, the stress would be merely that of shearing. He mentioned the matter as showing how necessary it was to be cautious in making use of alloys.

The Author. The AUTHOR, in reply, remarked that, in the Paper, he had not gone at all into the question of roofing-stays, referred to by Mr. Dobson. But it was a wide question, and he hoped some other member of the Institution would contribute a Paper on it; if not, perhaps at a later date he might be able to give an account of the practice of the London and North Western Railway. In answer to other questions raised by Mr. Dobson, he might say that the average mileage of the seven six-wheel-coupled engines fitted with copper stays was 261,000 miles, as against a total mileage of 284,978 miles for the engine fitted with copper-zinc stays (9 per cent. of zinc). The good result shown by this alloy, he would again mention, had been obtained in a comparatively low-pressure boiler (150 lbs. per square inch) and slow-working engine; whether the material would answer any better than copper in a high-pressure boiler and heavily-worked passenger-engine could only be decided by trial. As regarded the amount of arsenic which should be present in the plate and stay, he had no doubt that 0·3 per cent. to 0·5 per cent. in the plate, and not more than half that quantity, if any, in the stay, would be found satisfactory. The subject of fire-box stays was of the utmost importance, as he could realize, having been in charge of the boilers of the London and North Western Railway for 30 years, and having under his charge 3,000 boilers containing 2,500,000 stays. The position was not exactly a bed of roses, and great care was needed in trying experiments with new alloys. With regard

to aluminium alloys, if Mr. Pilkington would send him some The Author, of the aluminium-copper alloys he had referred to, he would gladly test them at the temperature at which they would have to work in a boiler, and would communicate the results to the Institution. If Mr. Pilkington would do that at once, he would take care that the results were added to the Paper, if so desired.¹ With regard to stays with solid heads, 40 years ago, when Mr. Ramsbottom had been at Crewe, many boilers had been stayed with iron stays with square heads inside the fire-box, but it had been impossible to keep them tight. That had been the case with engines working at 120 lbs. per square inch, not 200 lbs. or 210 lbs. as at the present time. The machine used at Crewe for heading stays was a pneumatic riveter of special construction. It worked well, and he would be glad to show it to any member who cared to go to Crewe. Formerly only a riveting-hammer had been used. He was very glad indeed if the Paper had been of any service to his brother members, and he would be pleased to help in any further investigations on kindred subjects.

The PRESIDENT remarked that the Institution would be much The President, obliged to the Author if he would, as suggested, furnish the results of tests of the material referred to by Mr. Pilkington.

Correspondence.

Mr. T. ANDREWS remarked that the enlargement of the crystal Mr. Andrews, grains of the copper-aluminium rolled rod (Figs. 25 and 26, Plate 5) when submitted to a temperature below redness for a short time, was a matter of great practical importance, which doubtless had frequently led to an alteration of the original physical properties of some metals subjected to particular thermal conditions, or which, from accidental causes, had become heated beyond the normal conditions of service. Accidents had doubtless arisen from this cause. In a Paper² on "The Effect of Strain on Railway Axles," he had illustrated the effects of temperature on the crystalline structure and resistance of railway axles, and had further demonstrated, at comparatively low temperatures, the

¹ The Author has not received from Mr. Pilkington the samples of his aluminium-copper alloys, and has therefore been unable to undertake the promised tests.—F. W. W. July, 1902.

² Transactions of Society of Engineers, 1895, p. 181.