

At the conclusion of the Paper the Chairman of the Association, Mr. C. H. Bailey, proposed a vote of thanks to the Author.

The vote of thanks was carried by acclamation.

Discussion.

Mr. Carpmael. Mr. RAYMOND CARPMAEL said that, on p. 233 the Author had stated that, as the result of a test, "about one hundred and six members were eliminated from the standard framing of the 57-foot corridor-third-brake coaches with a considerable saving in cost"; that was, presumably, the whole idea of the system of tests that was described in the Paper.

An idea of the completeness of the use of welding might be obtained from the Author's statement on p. 254 that "The only parts fixed by riveting or bolting are those which require fairly frequent removal, such as brake-work and axle-guard liners. Due to the elimination of rivet-holes, it has been found possible to use lighter sections . . ."; for many years it had seemed to him to be wrong, when fastening two pieces of steel together, to bore holes in them and then to fill up the holes with bolts, an extra thickness of metal being added to the plates to compensate for the weakening caused by the holes.

It was very interesting to learn about the extended use of welding in the L.M.S.R. wagon and carriage shops. Welding was used for some work on the G.W.R., such as for repairing coaches, but up to the present no large jobs, such as a roof or a bridge, had been constructed with welded joints; he hoped that such works would, in time, be welded. He would like to ask one question, namely, what tolerance was allowed on the fillet-welds, and what percentage of those fillet-welds outside the tolerance, or otherwise defective, would result in the rejection of a complete built-up frame?

Mr. Gibbins. Mr. FRANK GIBBINS congratulated the Author on his Paper. In 1932 his firm, the Gloucester Carriage and Wagon Company, received an order for twenty-seven all-steel electric coaches for the South Indian Railway. The railway company were anxious to reduce the weight of their existing stock, and in collaboration with Mr. B. G. White, M. Inst. C.E., of Messrs. Robert White and Partners, the engineers for the railway company, it was decided that welding would be a big factor in achieving the required result. The designs were made accordingly. Each train was made up of three articulated coaches, and the whole of the bogies, underframes and bodies were welded with the exception of the body-panels. Every detail of the bogie was fabricated and welded, and all steel castings were eliminated;

the use of ordinary cast-steel brackets was eliminated, the brackets Mr. Gibbins. being made up of $\frac{3}{8}$ -inch by $\frac{1}{2}$ -inch plates. The underframe, which was 51 feet long, was made up of 6-inch channels, the two solebars running through in one length, whilst the central longitudes were in short lengths and welded to the crossbars. An interesting test was made with that underframe. It was slung up by chains 2 feet on either side of the centre-line, and the ends were then brought down 16 inches and released; the action of the frame was like a piece of spring steel, and on examination no set had taken place and no damage had been done to the frame. He would not like to test a riveted frame like that. With that coach 2 tons was saved by welding, or 6 tons per unit, which enabled an extra trailer car to be added to the existing power unit.

His firm had recently built some 65-foot 6-inch welded wagons, which he thought were the longest welded wagons running in Great Britain. The underframe comprised two fish-bellied members, top and bottom plates being welded to another plate to form a beam. The frame had an inverted camber of $1\frac{1}{8}$ inch between the bogie centres. A distributed test-load of 40 tons was applied to the wagons, and with that load the camber was reduced to $\frac{3}{8}$ inch; after 24 hours the load was removed and the camber returned to the original $1\frac{1}{8}$ inch. The weight saved by using welding on that wagon was 2 tons.

Mr. H. E. ALLEN remarked that he was especially interested in Mr. Allen. the Paper, as, in addition to having practised as a civil engineer, for some years he had been general manager of one of the large rolling-stock companies. At the time very little welding was employed except for small component members in the details of the underframe. With regard to welding, he would ask whether any microscopic examination had been made; if so, had any sign of failure been observed?

The Author stated that "All steelwork was prepared to correct length, etc., as shown in the drawings, except the solebars, which were left slightly longer." Solebars were usually difficult to handle, and they should be correctly milled to length. Were they left slightly longer to allow for camber? If the solebars had to be cut to length when in position, would it not add considerably to the cost?

Regarding the interior equipment of rolling stock, he would like to point out that the use of double sliding corridor doors made egress very awkward, while sometimes the doors jammed.

He had also travelled a fair amount on the Southern Railway's main-line electric services, and when running around curves the coach would start to swing, gradually increasing to a shaking action;

Mr. Allen.

that motion was, he thought, due to the oscillation-springs being too weak. The travelling was very uncomfortable.

Professor Batho.

Professor CYRIL BATHO remarked that he was surprised that all the tests described had been static tests, as he thought that a railway coach was continually subjected to vibration from braking and varying conditions of loading; further, he had always understood that weakness, when it existed in welded joints, was a weakness in fatigue-strength, so that he would have expected that dynamic tests would have been carried out, at any rate on the welded elements, and possibly on the whole frame.

Mr. Dunster.

Mr. F. L. DUNSTER observed that, with the welded construction described, the body was built direct on to the underframe, whereas in the old method indiarubber body-pads were used; further, the new L.M.S.R. stock being built by various contractors, as well as that being constructed by the railway company, still employed body-pads. He would therefore ask the Author whether the welded cars described in the Paper were in the experimental stage, or whether the idea had been dropped and the old method been re-introduced.

Mr. Allen had commented on oscillation of the Southern Railway main-line electric trains; Mr. Dunster suggested that the oscillation might be caused from the fact that multiple-unit stock was employed, the train being driven both from the rear and from the front, giving rise to a pull-and-push action on the buffers. When ascending a gradient the leading motor-bogie would tend to sag relative to the rear bogie, thus making a certain amount of compression on the buffers, and creating a concertina action afterwards.

Mr. Crump.

Mr. BENJAMIN CRUMP asked how the camber, which was put in the frame when setting out for welding, was retained. When cross pieces were welded on to the solebars distortion always resulted, and the length of the members always shortened. He would like to know what method was adopted for keeping the frame straight when the welding was done. What was the Author's objection to overhead welding and vertical welding? It was impossible to rotate a frame 57 feet long and to keep it perfectly in camber while the members were welded on. Further, the suppliers of electrodes had produced a rod which was perfectly good in vertical and overhead welding, as well as in the touch-rod or free-hand welding.

Mr. Cheesley.

Mr. A. T. CHEESLEY remarked that he was very surprised that the L.M.S. Railway Company had spent so much money and time, and had given so much attention, to perpetuating the use of timber. Was it not time to adopt an all-steel construction? He thought that the results of the tests on the new design appeared to support that view, as the amount of steel used had been very considerably increased. Steel cant-rails, arch-rails and corner-rails had been

introduced, and he thought that coach-bodies should be constructed Mr. Cheesley. entirely of steel; at any rate, tests similar to those described should be carried out to compare the use of steel with that of timber.

He felt that the method of assembly of the frame left much to be desired, and he would mention, from his own experience, that there was a large amount of stress locked up in the frame which could be avoided; that opinion was apparently held by the Author, who stated, on pp. 257 and 258, that great care had been taken to prevent distortion and shrinkage, and that the total shrinkage of the carriage underframe was $\frac{5}{16}$ inch, while "other total shrinkages in width along the underframe varied from $\frac{3}{32}$ inch to $\frac{1}{8}$ inch." With regard to the wagon, the transverse shrinkage was from $\frac{1}{16}$ inch to $\frac{1}{8}$ inch, longitudinal shrinkage being up to $\frac{1}{8}$ inch. Mr. Cheesley noticed that the word "shrinkage" had been used, and he wondered if that meant that such a tolerance was necessary; he was sure that no inspector would pass a frame obtained from an outside supplier which departed from standard by anything like that amount. He did not consider that such tolerances as $\frac{3}{16}$ inch over the scroll-iron centres were necessary.

He observed that only arc-welding had been used. On the Continent, and in many other parts of the world, very little arc-welding was used in the construction of coaches and wagons, and he wondered why the L.M.S.R. had used arc-welding exclusively, instead of spot-welding. Remarkable Continental designs for rolling stock had been produced, but little was known of their costs. He would like the Author to give comparative costs of welded underframes for coaches and wagons as compared with the cost of riveted ones.

Mr. W. T. TOLHURST said that he was very pleased to note in the Mr. Tolhurst. tests which the Author showed that on no occasion did the welding fail. The failure was always in the woodwork, and that being the case he thought that the L.M.S.R. had progressed so far that they should build all-steel carriages and wagons.

With regard to the calculations of strength of the welds from the cross members to the solebars, the calculations for the bending moment, for instance, were, he thought, taken on the whole of the welding around the channel section. That hardly seemed right, because in the case of the bending moment the maximum stress was in the welds on the flanges; he would have thought that the safer way would have been to have calculated the moment of resistance of the section of the welds which connected to the flanges, since if a weld started to crack it would clearly start at those points. Although he was in favour of the use of welding, he was aware of its weaknesses. It was essential to remember them, especially when dealing

Mr. Tolhurst. with vibratory or alternating stresses. It was very important to base calculations only on the portions of the weld which were the most highly stressed. A very important case was where end standards were welded on to the headstocks. Only the top and bottom welds should be considered when calculating the strength, because they were the most highly stressed parts of the weld; if those welds failed, the side or vertical welds would obviously go very quickly. Recent tests had shown that weld metal, when subject to vibratory stresses, had failed at very much lower values than those found by the ordinary tensile tests. It was therefore essential, when dealing with joints subject to such stresses, to see that as much of the weld as possible was subject to a uniform maximum stress.

The last speaker mentioned that Continental wagons were largely spot-welded. He did not think it would be possible to spot-weld the underframes where fair-sized channel-sections were used, but he agreed that it would be advisable to attempt to spot-weld the panels on to the side frames when steel side frames were used.

Mr. Jackson. Mr. HARRY JACKSON remarked that there was one question he would like to ask regarding the order in which the welding took place in the production of the underframe. He thought that the Author had said that the welding was started at the middle and the welders worked towards the ends. His reason for asking the question was that, in the welding of some light lattice girders for a footbridge, special care had not been taken, and as a result considerable buckling had occurred in the main longitudinal member. Some such buckling might have taken place in the frames described by the Author, possibly resulting in unequal stress-distribution. Was that so?

Mr. Green. Mr. V. E. GREEN said that he would like to ask the Author whether any X-ray examination of the welding had been carried out during the early stages of construction. The point at which Mr. Green was most surprised was the general absence of diagonal bracing. Cruciform bracing was employed in modern motor-car construction, yet in the main underframe of the coach diagonal bracing was entirely lacking, although there was a certain amount of bracing in the vertical frames.

He thought that the new form of steel coach would introduce a fair amount of noise due to drumming. When travelling in G.W.R. trains he had been surprised at the drumming in the corridors of coaches with all-steel frames and steel panelling.

A point he wished to raise was the method of painting for protection from corrosion. When so much steel was introduced adjacent to the floor, he thought that corrosion might be experienced through dust from the track and from passing trains. From some tests he had carried out recently on wagons built about 50 years ago,

with wrought-iron axles, it was found that quite a number of axles Mr. Green. had failed through corrosion fatigue; it seemed quite common, however, in lavatory coaches to see axles which were subject to corrosion fatigue from the ordinary discharge, and he thought that steps could be taken to obviate that occurrence.

The AUTHOR, in reply, said that in determining the size of welds The Author. it was advisable to allow an extra $\frac{1}{4}$ inch or $\frac{1}{2}$ inch on the calculated length of the weld, as stated on p. 242. When inspecting welds, the throat dimension was tested with a weld gauge and no weld was passed which was under size. If the weld was below the specified size an extra run of weld metal was added to bring it up to size, and hence the possibility of having to reject a complete frame because the welds were under size did not arise in practice.

He was interested in the details given by Mr. Gibbins of all-steel welded coaches for the South Indian Railway. Mr. Gibbins mentioned that the order for those coaches was received by the Gloucester Carriage and Wagon Company in 1932, and in *The Welder* of February, 1934, was a description of these coaches, with the remark that the Gloucester Carriage and Wagon Company "have just completed" the order. It was interesting to note from that description that the saving in weight on the welded underframes was nearly two-thirds of a ton, or about 13 cwt., which weight reduction was about equal to that obtained by the Author.

With regard to the 65-foot 6-inch welded wagons for transporting rails and ballast, according to *The Welder* of December, 1935, those bogie wagons weighed 18 tons 2 cwt. It would be found that the 2 tons reduction in weight represented about the same percentage reduction in weight on the welded underframe as was obtained on the wagon described by the Author. In the latter case the weight reduction on the frame alone was about 20 per cent.

Mr. Allen had asked whether any microscopic examination had been made of the welds. No microscopic or X-ray examination had been made of the finished welds as no really satisfactory method of doing so had yet been devised. Many microscopic tests of the weld metal had been carried out in the Company's laboratories. As regards the solebars being left slightly longer, that was done on the first coach underframe as an experiment to ensure that any shrinkage due to welding would be allowed for. The ends were then carefully finished to size, but on later underframes the ends were milled as the necessary length had then been determined. The matter of double sliding doors was irrelevant to the Paper, as they were not used in the design described nor had they been referred to. Similarly, the riding of the Southern Railway's main-line electric coaches was not a matter which came within the scope of the Paper.

The Author.

Professor Batho had mentioned that the tests were static and not dynamic. Admittedly, some of the tests were static, but dynamic tests were carried out also, such as the alternating tests referred to on p. 257, impact tests on welds, and shunting tests on the coach underframe and bogies. A welded wagon was given shunting and impact tests at speeds ranging from 5 up to 30 miles per hour, and was finally tested to destruction to determine the value of the welds under dynamic conditions. Further, the Author made a thorough search of literature on welding published throughout the world, and took full cognizance of welding tests and the relation of dynamic, fatigue, impact and static values, before determining the values of the permissible stresses given on p. 240 which were fixed for the dynamic conditions of railway vehicles. Probably few coaches or wagons had been the subject of so great a number of tests of every kind, and the completely successful running of the vehicles described over a period of 2 years vindicated the methods adopted.

In reply to Mr. Dunster, the Author had stated that no rubber pads were placed between the steel key-sheeted floor and the underframe. Experiments were made to determine whether that type of floor allowed more noise to enter the coach than in the case of a coach having rubber pads, but no difference could be determined. It might be added that it was a well-established practice on several railways to put a steel floor directly on to the underframe.

Mr. Crump had asked how the camber was retained in the underframe, but no difficulty whatsoever was experienced in that direction. In the Author's opinion it was an exaggeration to state that "it was impossible to rotate a frame 57 feet long and to keep it perfectly in camber while the members were welded on." If proper attention were paid to welding procedure no difficulty would be experienced in keeping the camber in the underframe, but it should be borne in mind that the design had to be one that was suitable for welding, otherwise some difficulty might be experienced.

With regard to vertical and overhead welding, it was best avoided, as the possibility of a poor-quality weld was much greater than with downhand welding, as practical experience of welding would quickly prove. The extra cost of electrodes suitable for overhead and vertical welding would more than pay for the cost of rotating jigs if a number of underframes were being built. Several speakers had expressed their opinions regarding all-steel coaches and wagons, but that question of the L.M.S.R. Company's policy was not within the scope of the Paper.

The Author was very surprised at Mr. Cheesley's remarks with regard to the method of assembly of the coach underframe, and he suggested that such remarks were not based on practical welding

experience; the Author was fully satisfied with the methods he The Author. adopted, as the locked-up stresses were reduced to a minimum by the control of welding procedure and the use of electrodes of high ductility. With regard to the fact that "Mr. Cheesley noticed that the word shrinkage had been used, and he wondered if that meant that such a tolerance was necessary," the Author had stated that it had to be borne in mind that shrinkage was one of the principal difficulties experienced in welding, and that it was practically impossible to eliminate it; by experience, however, it was possible to reduce it to a minimum and to produce welded frames as accurate as riveted frames were. Tolerance was a totally different matter from shrinkage, and no welding tolerance was stated in the Paper, but if a tolerance were fixed the degree of accuracy that the work warranted would have to be considered, and a long time would elapse before wagon frames would be built to micrometer gauges.

Spot-welding was a useful process for joining thin plates, but it had no advantage over electric-arc welding for building underframes. With electric-arc welding it was possible to obtain up to a 100-per-cent. joint efficiency, whereas with spot-welding the maximum efficiency would be no higher, in most cases, than that of a riveted joint. The Author had tested a number of spot-welded joints similar to those that would be used for wagon frames, and he was not very satisfied with their quality, although they had been supplied by one of the firms dealing with that class of welding plant.

The Author was interested in Mr. Tolhurst's remarks regarding the calculations of welds. It was very important in calculating the dimensions of welds to take into consideration not only the bending moments referred to by Mr. Tolhurst, but also shear and other stresses. It would be seen, on p. 252, that the stresses in the flange welds due to bending moments had been included in the calculations. The Author was of the opinion that the subject of the design of welds had not received the investigation and research that such an important part of the development of welding technique warranted.

With regard to the question by Mr. Jackson as to the order of welding, it would be a little difficult to state methods which would be applicable to all classes of fabrications, as it was largely a matter of experience. The methods mentioned on pp. 254-6 and 277-8 had produced very satisfactory results. Mr. Green had referred to the absence of diagonal bracing, and stated that "in the main under-frame of the coach diagonal bracing was entirely lacking." That was an ill-considered statement, and he would suggest that if Mr. Green examined the drawing of the coach underframe he would find it adequately braced. Experiments had been made to determine if the new type of coach was noisier in running than other types of

The Author. coaches, but practically no difference could be ascertained. The underframes were painted with a specially-prepared paint and the key-sheeting used for the floor was galvanized, and so far no trouble had been experienced due to corrosion from moisture.

The Council invite written communications on the foregoing Paper, which should be submitted not later than 2 months after the date of publication. Provided that there is a satisfactory response to this invitation, it is proposed in due course to consider the question of publishing such communications, together with the Author's reply.