Discussion.

Mr. W. H. Preece, C.B., President, said it was his pleasing duty to propose a vote of thanks to the Authors of the two Papers for having brought before the Institution a subject so extremely interesting and so unquestionably valuable. It must be a matter of gratification to many of the old members to find that the pioneer work of their old friend David Kirkaldy was being carried on so satisfactorily and so ably by his son. The Papers were both highly scientific in their aim, but the one was essentially mechanical and experimental, and the other a searching into the depths of things with one of those mental eyes which Science had imparted to observers. Prof. Sir William Roberts-Austen had not only shown the composition of steel as it was, but, in his Paper, he had gone far enough to indicate the history of that steel, and to read the process of cementation, and all the changes brought about by temperature in its various stages, since its preparation. The subject had been very brilliantly and beautifully put before the members, and he was sure they would with acclamation carry a resolution giving a vote of thanks to both the Authors. Mr. Preece.

Sir William C. Roberts-Austen, K.C.B., exhibited upon the screen the following photo-micrographs, to illustrate the various forms in which carbon might occur in iron:—(1) A variety of iron containing about $\frac{4}{10}$ per cent. of carbon, which had been slowly cooled. The magnification was about 800 diameters. The white parts represented the ferrite, and the dark portions the grains of pearlite; that was, the alternate layers of ferrite and of carbide, Fe_3C, which constituted the pearlite. Of the few round photographs, that was the only one which in any way represented a steel rail, but he thought it would be well to show the mode of existence of the carbon under varied thermal treatment, in order that it might be seen how complex the question really was. (2) Nearly the same variety of steel, but, instead of being slowly cooled, it had been quenched from a temperature of 750° C., and the carbide, instead of existing as pearlite in alternate laminæ of pearlite and carbide, was aggregated into knotty lumps, to which the name Troostite had been given. As far as he knew, that variety of carbide seldom occurred in a steel rail. (3) A variety of steel which contained some 1·2 per cent. of carbon, and had been very slowly cooled. The slide showed the mass of the Sir William Roberts-Austen.

Sir William Roberts-Austen.

material made up of pearlite, *i.e.*, alternate bands of carbide and of ferrite, but there was a mass of carbide concentrated into a broad band which would be known as banded cementite. (4) The same steel, quenched from a bright red heat, and exhibiting the needle-like aggregation of the carbon known as martensite. (5) The same steel, quenched from a bright red heat and tempered. (6) A variety of steel containing 1·6 per cent. of carbon heated to bright redness, and quenched in iced brine. It was seen how totally different the aggregation of the carbide was from any of the preceding slides. To that variety of carbide the French had given the name of Austenite. An exceedingly good rail, which Mr. Kirkaldy had been kind enough to send him, was shown in section, in Fig. 15, Plate 3. In beginning the micrographic examination of a rail, it was well to coat one side of such a section with varnish, and to pickle the whole of the rail section in sulphuric acid. The result was that it could be seen how certain of the materials were distributed, and the rails varied widely in the way they were acted upon by sulphuric acid. Rails rich in manganese usually showed, when treated by sulphuric acid, a very minute structure, considerably finer than the rail in question, but, if the section was carefully examined it would be seen that round the outer edge there was a widely different structure from that which occurred in the centre. In the same way the drawing out of the web by rolling had extended certain portions of the material, some of which were slag. The edge of rail section showed at once what portions of the rail best deserved micrographic examination, and the sections he was about to throw on the screen were taken respectively from the points marked A, B, C, D, E, F, G, and H on Fig. 15, Plate 3, which is a photograph of the entire rail section. A and B were micrographs taken from the extreme upper corner of the running surface of the rail shown in Fig. 15 and they indicated the peculiar structure which was obtained by what Mr. Kirkaldy called "hammer-hardening." C, Fig. 9, was another section taken very near the running surface, showing broad bands of ferrite enclosing masses of pearlite. D, Fig. 10, was a specimen taken near the centre of the head. E, Fig. 11, was from the outer portion of the centre of the web, and in this case the ferrite existed in the form of longish bands instead of the network which enclosed the pearlite. That rail, so far as his experience went, was somewhat exceptional, as he had not met with another case in which the ferrite had been so much extended as in that particular case; the rail was a very good one. In F, Fig. 12, the elongation of the ferrite bands was still more marked. G, Fig. 13, was a section taken near the bottom of the rail; the area of pearlite had become larger, and the ferrite restricted to narrow, mesh-like bands, while in H, Fig. 16, extreme base of the rail, the under surface was shown. The long line structures had entirely disappeared, and the mesh-like structure reappeared. Fig. 17 gave magnification of about 850 diameters of the centre of a rail. It showed that the carbide, which under lower magnification was very small patches, resolved itself into much the same banded alternations of black carbide and white ferrite as seen in the first slide. The upper layer of a rail was often very thin and might be easily removed by planing; it differed from the rest of the rail beneath it. Sir William Roberts-Austen.

Mr. W. G. KIRKALDY exhibited photographs upon the screen illustrating the minute hair cracks referred to in the Paper, transversely to the length of the rail, and symmetrically arranged at practically equal distances apart, Figs. 18 and 19, Plate 3. The rail had been subjected to skidding action, and was very hard on the surface; no tool could be found to cut it at the top surface, so that it was cut from the rear and snapped off. Where trouble had arisen it was evidently due to some of those cracks which had developed while the rail was in the line. Although the bulk of the rail might not be very much damaged there was a risk of some of the cracks penetrating more deeply. He also illustrated a specimen, Fig. 20, prepared from the head of the rail and tested by crushing. When it was prepared in the lathe there was only a slight amount taken off the top surface to true it. At that time the cracks could not be seen by the eye, but they had developed under pressure. The cracks were all transverse to the length of the rail, as induced flaws were always found to occur. Another photograph, Fig. 21, illustrated a rail from the L. B. & S. C. line, exhibiting the cracks in a very symmetrical manner. It was discovered owing to a piece having scaled off. Whether that was an original defect in the rolling of the rail it was difficult to state positively, but it had all the appearance of being so. There was a specimen on the table which pointed to a surface crack having penetrated vertically downwards, and then turned and worked its way horizontally. Mr. Kirkaldy.

Sir LOWTHIAN BELL, Bart., said that Sir William Roberts-Austen had applied the word "famous" to a particular rail, and he believed that was the first occasion on which he had ever heard that appellation applied to a rail, but never in his life had he met with one more worthy of that distinction. The number of rails which were found broken on railways was, as nearly as he Sir Lowthian Bell.

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had been able to compute, 1 in 3,500. It was remarkable that until the rail referred to early in the Paper gave way no accident had been heard of attended with any serious circumstances. Notwithstanding that piece of statistical knowledge, the fracture of that rail created dismay, not only in the minds of travellers, but in the minds of ironmasters themselves; and one of the first attempts to cure it was to increase the size of the head of the rail, the propriety of which, he understood, Mr. Kirkaldy doubted. He also was inclined to do so, because if the change referred to by Sir William Roberts-Austen was correct, the longer a rail was exposed to the rolling and percussive action on the line the more brittle it probably would become. With regard to the cracks in the rail, he should like to know, before he proceeded further, to what extent the Author, who had performed all those beautiful experiments, had had an opportunity of comparing the quality of a rail of any particular section, that was, with regard to its composition, its brittleness, or the reverse. He mentioned that, because it was quite easy almost to prove anything by an examination of rails; in fact, the behaviour of rails on the line was so capricious that he found himself always in a position of considerable difficulty in making any very strong assertion in regard to any particular event, because he had found over and over again that the opinion that he came to after a somewhat extensive course of examinations was contradicted by the very next experiment he made. He might perhaps be permitted to say that for 25 years of his life he was a rail manufacturer, and for over 25 years he had been one of the directors of the North Eastern Railway Company, and he naturally took a great interest in a question which at that time did not appear to receive much attention from railway engineers themselves, viz., what was the safe time to allow a rail to remain on the line? For the last 5 years he had been engaged in tabulating all the results of the rails that had been taken up on the North Eastern Railway, and the conclusion he had come to was, as he had said before, first, the great difficulty attending the question; and, secondly, the very contradictory nature of the results obtained. With regard to the cracks, he did not pretend that it was not highly desirable to avoid the existence of those small fissures in the rail, but he was not quite sure that the very prominent importance ought to be attached to their existence which Mr. Kirkaldy had given to them. The top member of the rail when it received the train was put into a state of compression, and the effect of that compression, in his opinion, would tend to seal up

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the small fissures. He was very anxious to ascertain experimentally how far the fissure—not in iron or steel—was detrimental to stability and strength, and for that purpose he had experimented on slips of plate glass, one or two of which he had on the table. These were supported on bearings 10 inches apart, and weights were applied to a knife-edge resting on the centre of the slip of glass. The glass which was not scratched at all withstood a weight of about 40 lbs. before it broke. He then scratched the glass with an ordinary glazier's diamond and applied a weight, the scratch being on the under side, and the breaking weight was 16 lbs. He then tried another sample, having the scratch on the upper side of the plate, and within a few pounds it was as strong as the glass without any scratch upon it. That was the kind of action which appeared to him was very likely to take place in the case of rails, and he attached very little danger to the fact of passing over a broken rail, and for the same reason, viz., that the two ends of the fractured rail, in point of fact, were supporting each other, and further danger was thus avoided. He did not know whether Sir William Roberts-Austen had been able to connect chemical composition with the separation of steel into those very curious and highly interesting divisions, of which he had given such brilliant examples. If that was the case, then there was no great difficulty. He supposed, first and last, he must have taken a part in the analysis of about ten thousand specimens of rails, for about that number had passed through the laboratory of the North Eastern Railway during the last 15 years. That was about the most perplexing of all the problems he had had to deal with. He had tabulated several hundreds of specimens according to the quantity of metals and metalloids contained in the rail and there was no kind of harmony between weakness and great purity; and on the other side there was no harmony between great purity and great strength. He had, therefore, come to the conclusion that great care was necessary in forming any decision too rapidly on all subjects connected with rails. The catalogue of difficulty was not exhausted in speaking of the rails themselves, for the changing character of the traffic to which they were submitted had also to be regarded. At such a station as Newcastle-on-Tyne, the money receipts were probably twenty times those of many remote agricultural districts. Consequently the wear on the rails was immensely greater in the former, than in the less frequented localities. At the same time it might be from some defect in the laying of rails. Upon one occasion, a breakage of some dozen

Sir Lowthian Bell. or more rails had occurred at a small place called Warcup, near Kirkby-Stephen, which any one conversant with the geography of Cumberland would know was a very remote place, having very little traffic; but, possibly from some fault in the laying, fourteen rails gave way in that place. There had been others equally difficult to account for. He did not know whether it might interest the Institution to have, when the work he was busy with at the present moment was completed, some account of the conclusions to which he had come with regard to the North Eastern Railway. If it should be the wish of the President of the Institution, and with the permission of his colleagues on the Board of the North Eastern Railway, he should be glad to communicate them to the Institution. He hoped to obtain that permission from his colleagues, not only in the interests of railways generally, but in the interests of scientific manufacture. With regard to the manufacturers aiming at any particular constitution of the rails, that was a very much more difficult question. When it was conceived that into a great cauldron about 15 tons or 16 tons of metal were poured, and that in 15 minutes the whole of that metal had been converted into Bessemer steel, it would be seen that it was almost impossible to calculate with any degree of nicety the character of the product. With regard to the ends of rails, Mr. Kirkaldy very properly drew attention to the fact that a particular end of the rail might be imperfectly welded; that was very likely. Unfortunately breaks took place, as was known very well, at parts distant from the end. He had proved one thing with regard to the character of steel as a whole in an ingot, viz., that the rail made from the middle and from the bottom of the ingot was superior in quality to that made from the upper end, and that was precisely what a Bessemer steel manufacturer would expect. The blow-holes, as they were termed, and the scoriacious portions necessarily floated to the top, and in the meantime the steel was becoming more and more viscous in its character, and there was a greater difficulty in such impurities escaping. As a matter of fact, as might be expected, that was the worst part of the rail. He did not know that the plan pursued by railway companies was most likely to overcome the difficulty, for when they bought rails, as they had done, in very large quantities, made from very good material, at the unremunerative price of £3 15*s.* 0*d.* a ton, he thought it would be allowed there was not very much encouragement to the rail-maker to make a very good article.

Mr. Snelus. Mr. G. J. SNELUS thought it would be very interesting and very important if the chemical analysis of the rails which had been so

Mr. Snelus.

elaborately tested by Mr. Kirkaldy could be given. With that information the members might be able to draw conclusions which they certainly could not without them. He admitted that the mechanical treatment was probably more important than the chemical knowledge of the rails in question; but, at the same time, he thought it was not wise to separate the two subjects; they should go hand in hand in order that the members might have full and complete information to study the question fully. He should like to ask Mr. Kirkaldy if he had had opportunity of observing whether the cracks were developed in flange rails to the same extent as they appeared to be developed in bull-head and double-headed rails; it seemed that the flaws occurred mainly over the chairs. Whether the occurrence of the flaws on the chairs was due to the hammering action there, with the rail being supported as on an anvil, or whether it was that the flaws were due to the action of the wheel when it passed in the middle, between two chairs, causing the head of the rail over the chair then to be in tension was a point which required further investigation; but if it was the case, might it not be that, after all, the flange rail, which was so much in favour with engineers on the Continent and in America, had yet points of advantage over the bull-headed rails, with the numerous anvils which were used to support them? He agreed that it would be probably an advantage to add more to the height of the web of the rail and put rather less matter into the head. He thought that the larger the mass of metal in the head, the more chance there was for the cracks to be developed. Then Mr. Kirkaldy also suggested that it might be advisable to ascertain whether a different chemical composition would stop the development of the cracks, and he suggested that it might be advisable to try an alloy of nickel, or of chromium, or of manganese. Of the three metals mentioned, he thought the chances were decidedly in favour of nickel. He thought there was a good deal yet to be learned with respect to the alloy of nickel and iron. It was known that in the nickel armour-plates, the incipient cracks, which were developed on the impact of the shot, were not developed to nearly the same extent in the nickel plate as they were in the old ordinary steel plate. It might be that the nickel alloy of iron would prevent those flaws in a somewhat similar way to its effect on the armour plate. It was quite true that the expense of the alloy was a point of very great importance. There was no doubt that, in order to produce a nickel alloy which would be of any value at all, at least 20*s*. a ton would have to be

Mr. Snelus. added to the cost of the rail. At the same time that 20*s.* extra price might be very well earned, and he thought that experiments in the direction suggested by Mr. Kirkaldy of using a nickel alloy ought to be tried. With respect to the Paper by Sir William Roberts-Austen, he would like to ask whether the Author had ever attempted to obtain a photo-micrograph of a section at right angles to such sections as were shown in Plate 2. He should like to know how deep those masses of ferrite and pearlite went; he supposed it would be possible to measure them. At present all the diagrams that he had seen appeared to be of only one surface. He thought it would be extremely important if they could be examined at right angles to the surface. Photographs of the object to be examined might be taken first, and then a photograph of a carefully-prepared specimen at right angles to that surface. He should like to ask also whether Sir William Roberts-Austen had ascertained whether the flaws found in the heads of rails followed the line of the ferrite or of the pearlite, or whether they cut quite clean through both the components of the metal. He thought these were all questions which were very interesting, and it would be worth while to have some further information about them.

Mr. Ross. Mr. ALEXANDER ROSS exhibited Tables showing chemical analyses of some of the rails referred to in the Paper. Table I proved that a rail did produce different analytical results at different portions along its length. He believed that different results would be obtained from different points, even in the surface of the cross-section of a rail. In any case, the Tables associated the analytical results with the mechanical, and he thought in some instances they offered a warning rather than otherwise.

TABLE I.—AVERAGE ANALYSIS OF TEN DIFFERENT TESTS OF RAILS ALLUDED TO BY THE AUTHOR, *Figs. 1–8.*

——	Maximum.	Minimum.	Average.	Difference between Maximum and Minimum.
	Per cent.	Per cent.	Per cent.	Per cent.
Carbon	0·540	0·234	0·464	0·306
Silicon	0·130	0·038	0·109	0·092
Sulphur	0·106	0·065	0·085	0·041
Phosphorus	0·125	0·065	0·083	0·060
Arsenic	0·052	0·026	0·041	0·026
Manganese	0·493	0·300	0·443	0·193
Copper	0·060	0·047	0·053	0·013
Iron	98·826	98·621	98·722	0·205

TABLE II.—ANALYSIS OF THE EXTREMES OF THE TWELVE WORN RAILS REFERRED TO BY THE AUTHOR AT pp. 163 AND 164. Mr. Ross.

——	Rails taken from Line between Sykes Junction and Stow Park.		Rails taken from the Line near Misterton.	
	Hardest.	Softest.	Hardest.	Softest.
	Per cent.	Per cent.	Per cent.	Per cent.
Carbon	0·382	0·285	0·508	0·368
Silicon	0·029	0·021	0·091	0·050
Manganese	0·414	0·273	0·844	0·621
Sulphur	0·060	0·060	0·063	0·072
Phosphorus	0·126	0·107	0·066	0·053
Arsenic	0·017	0·015	0·023	0·022
Copper	0·046	0·043	0·016	0·016
Iron, by difference	98·926	99·196	98·389	98·798

TABLE III.—ANALYSIS OF RAIL REFERRED TO BY THE AUTHOR AT p. 150.

——	Rail Head.	Rail Web.	Rail Bottom.
	Per cent.	Per cent.	Per cent.
Combined carbon	0·340	0·350	0·380
Silicon	0·062	0·054	0·052
Manganese	0·478	0·486	0·446
Sulphur	0·065	0·070	0·080
Phosphorus	0·110	0·118	0·130
Iron, by difference	98·945	98·922	98·912

Table II dealt with rails which gave very good mechanical results, and therefore were very interesting. Table III gave an analysis of the rail referred to by Mr. Kirkaldy as an ideal rail. There again the connection between the mechanical and the chemical results was exceedingly interesting. He was anxious to learn what was the ideal, not only chemically but mechanically, and what tests should be looked for that would produce the best possible rail. He would be interested to know whether the Bessemer process was preferable to the Siemens-Martin process, or to have a comparative statement concerning them. It was desirable to know what was the best process or the best rail, even regardless of price. In two distinct parts of the Paper the Author had asserted his opinion that harder steel rails ought to be used. He would not traverse that opinion, but he had his doubts on the subject. It would be interesting and valuable if that matter were discussed by those thoroughly acquainted with the subject.

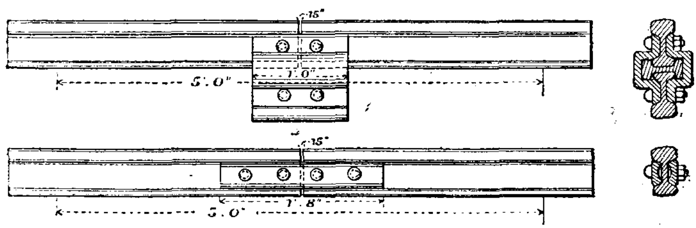
Mr. R. PRICE-WILLIAMS considered that the Author had in the Paper valuably supplemented the important and exhaustive re- Mr. Price-Williams.

Mr. Price-Williams. searches of his eminent father. Regarding the chemical tests, he was very glad to see on the walls the Tables prepared by Mr. Ross, which supplied, to a great extent, that omission in the Paper. He was quite certain that, having regard to the effects of the hammer hardening caused by the impact of the trains, it was of the highest importance that more light should be thrown on the subject, more especially in relation to the nature of the chemical constituents of the rail. Recent experience in the United States had shown that the low percentages of carbon which engineers were accustomed to in England did not suit the requirements of the traffic in the States, where percentages as high as 0·7 of carbon were, to his knowledge, required in the specifications of recent rail contracts, confirming what the Author had drawn attention to, and the view he (Mr. Price-Williams) held that what was wanted was a harder and tougher class of rail. Another important factor in the question was, undoubtedly, one which the late Mr. David Kirkaldy had always attached great importance to, namely, the amount of traffic tonnage the rails had been subjected to. He was aware that objections had been raised as to the difficulty in furnishing this information. He might state, however, that in the case of the Great Northern Railway, Mr. Johnson was kind enough to furnish it in the case of all the tests he (Mr. Price-Williams) had had carried out at Messrs. Kirkaldy's works; the possibility of slight errors in large quantities of that kind did not count at all, and he maintained that in spite of these objections the means were afforded of easily obtaining the requisite information from the accurate records which were kept of the train service. With regard to what the Author had said as to the inverted rail tests, the reversible rail was in very general use at one time, and a great deal of experience had been obtained of the objectionable feature the Author had laid so much stress upon, namely, the increased tendency of the rail to snap when the head, after having been subjected in compression to the enormous weight and speed of the traffic, was afterwards put into the reverse position in tension. This in fact was one of the numerous reasons which had led to the abolition of the reversible rail; in addition, there was the very objectionable and dangerous feature resulting from the galling of the under side of the rail in the chair to which the Author had drawn attention. He, however, concurred with him in thinking that the reversible rail tests afforded a very valuable aid in detecting any flaws in the material. One of the chief causes, undoubtedly, of this hammer

Mr. Price-Williams.

hardening was, as the Author had pointed out, due to the weakness of the rail at the joints; and the rapid deterioration of the head of the rail over the chairs nearest to the rail-joint was also, in his opinion, in a large measure due to the same cause. Another most objectionable feature in the roadway at the present time was the much closer spacing of the sleepers at the rail-joints, which was rendered necessary owing to the great weakness of the road there; the inequality in the spacing of the sleepers this occasions was, however, one of the chief causes of the hammer hardening effects alluded to in the Paper. In his opinion, next to improving as far as possible the quality of the material, the attention of railway engineers should be directed to the strengthening of the rail-joints so as to admit of the sleepers being equally spaced. As regards improving the quality of the material, the Author had referred, but only incidentally, to the question whether the strength and toughness of the rail might not be increased by the

Figs. 21a.



Scale ½ inch = 1 foot.

admixture of a small percentage of nickel; of the effect of that metal he could not speak. He might state, however, that a short time ago, with Professor Arnold's assistance, he had some steel made containing about 0·18 per cent. of sesquioxide of chromium, which the late Mr. Kirkaldy tested, and was so struck with the results that he consulted him on the subject, as, in addition to largely adding to its tensile strength its resistance to compression, upon which the Author laid so much stress, was increased by about 30 to 40 per cent. He was very pleased to learn from Mr. F. W. Webb that he was now using, with very satisfactory results, a mixture of chromium in his steel, and he was in hopes he might have been present that evening to give the results of his large experience on the subject under discussion. He (Mr. Price-Williams) had only to add that he exhibited at the meeting the results of his own efforts to strengthen the road, in the shape of a specimen of vertically and laterally fished rails, *Figs. 21a*, which

Mr. Price-Williams. had been tested recently by Messrs. Kirkaldy, side by side with specimens of Midland Railway fish-plates and rails kindly furnished him for the purpose by Mr. McDonald. The results of these tests showed that the vertically and laterally fished rails, as they might properly be considered, added very largely indeed to the strength of the road, as would be seen from a summary of the results of these comparative tests shown in the appended Table, from which it would be seen that the deflections and permanent sets of the Midland Railway Company's heavy 100-lb. rails, when fitted with his fish-plates, were only one-sixth of what the Midland Company's fish-plates experienced under precisely similar conditions of test, and that while the latter fish-plates deflected over 6 inches, and completely gave way (as the permanent set was the same) under a central load of 20 tons; the deflection of the vertical and lateral fish-plates only amounted to 0·82 inch, and with a permanent set of 0·38 inch, which with 3-foot bearings (instead of the 5 feet used in the tests) would be equivalent to a deflection of only 0·18 inch with no appreciable amount of set. The vertical fish-plates were only 1 foot in length and with only one fish-bolt on either side of the rail-joint, while the Midland fish-plates were of the ordinary type, 1·6 inch in length with two fish-plate bolts on either side of the rail-joint.

ABSTRACT FROM MESSRS. KIRKALDY'S TESTS, 7 OCTOBER, 1898.

Description.	Dimensions, Fish-Plates.	Weight per Yard.	Stress in Lbs.; Deflection and Set.							
			10,000	15,000.	20,000.	25,000.	30,000.	35,000.	40,000.	45,000.
		Lbs.								
Deflections, Midland Railway Company's 100-lb. rail, Price-Williams' fish-plate	Joint 12 ins. long	Rails 100·0	0·09	0·21	0·31	0·36	0·44	0·56	0·67	0·82
Sets	..	..	..	..	0·10	0·12	0·15	0·22	0·29	0·38
Deflections, Midland Railway Company's 100-lb. rail, Midland Company's fish-plate . . .	Joint 20 ins. long	Rails 100·0	0·08	0·20	0·88	1·47	2·42	3·40	3·79	6·57
Sets	..	..	..	..	0·64	1·20	2·09	3·05	4·35	6·09

Mr. Inglis. Mr. J. C. INGLIS thought the railway contingent of the Institution would be exceedingly thankful to the Authors of the two Papers for presenting such a complete statement before them, and one which, he felt bold to say, would set the fashion largely in future rail tests. On p. 141 of his Paper, Mr. Kirkaldy stated that

Mr Inglis.

his father advocated, and had hoped to see adopted, standard sections for rails of definite weights, as well as standard specifications as to the quality of the steel. That was a subject to which he thought the Institution might give a little attention, and he was afraid American engineers had given the lead to Englishmen. In 1889 the American Society of Civil Engineers had, after an exhaustive inquiry into the most economical forms of rails, adopted standards, and they had designed them on the principles which they concluded were those advocated by the large majority of the Members of the Institution and experts in rails. They had designed rails from 100 lbs. downwards by 5-lb. intervals to 40 lbs. He had visited Messrs. Carnegie's works in the autumn of 1898, and he was informed that the adoption of those standard sections of rails was largely on the increase. He need not point out that the adoption of a standard rail meant the abolition, as one manufacturer expressed it, of his 10-acre plot for spare rolls, thus enabling the manufacturer to change, with greater freedom, the old rolls for the new, and so deriving a higher class of output on the whole. As to the quality of the rails, he had occasion, not very long ago, to make inquiry in America about a large lot of rails, and he sent over the English specification. His experience was not quite in accordance with that of the last speaker, because he obtained the answer that they would be very glad to supply the rails on the following specification:—

THE CARNEGIE STEEL COMPANY'S STANDARD SPECIFICATIONS FOR STEEL RAILS, JANUARY 1, 1897.

Chemical Composition.

—	60 Lbs. and under (29·76 Kilograms per Metre).	Over 60 Lbs. and up to 80 Lbs. (29·76 Kilograms to 39·68 Kilograms per Metre).	Over 80 Lbs. and up to 100 Lbs. (39·68 Kilograms to 49·61 Kilograms per Metre).
	Per cent.	Per cent.	Per cent.
Carbon	0·35 to 0·45	0·40 to 0·50	0·45 to 0·55
Phosphorus . .	Not to exceed 0·10	Not to exceed 0·10	Not to exceed 0·10
Manganese . .	0·60 to 0·80	0·70 to 0·90	0·80 to 1·00
Sulphur . . .	Not to exceed 0·05	Not to exceed 0·05	Not to exceed 0·05

Weight and Section.—The weight of the rail shall be maintained as near as possible to that specified in contract. A variation of 1 per cent. for individual rails and ½ per cent. for an entire order will be allowed. Rails shall be accepted and settled for according to actual weights. The section of the rail rolled shall conform as accurately as possible to the templet furnished by the Railroad Company, consistent with the above clause relative to specified weight. An allowance in height of $\frac{1}{64}$ inch (0·40 millimetre) under and $\frac{1}{32}$ inch over will be permitted. A perfect fit of the splice bars, however, shall be maintained at all times.

Length.—The standard length of rails shall be 30 feet (9·144 metres). Shorter rails to the extent of 10 per cent. of the entire order will be accepted

Mr. Inglis. in lengths of 28 feet (8·534 metres), 26 feet (7·925 metres) and 24 feet (7·315 metres). No rail shall vary more than ¼ inch (6·35 millimetres), either under or above, from the prescribed length.

Branding.—The name of the maker and the month and year of manufacture shall be rolled in raised letters on the side of the web, and the number of the heat shall be stamped on each rail.

Drilling.—Circular holes shall be drilled in accordance with specifications of purchaser. They must be accurate to drawing and dimensions furnished in every respect, and free from burrs.

Finishing.—Rails to be straightened while cold, and prior to shipment must have the burr occasioned by saw-cutting removed, and the ends made clean. They are to be free from mechanical defects and flaws of all kinds.

Inspection.—The inspector representing the purchaser shall have free access to the works of the manufacturer at all times while his contract is being executed, and shall have all reasonable facilities afforded to satisfy him that the rails are being made in accordance with specifications.

The manufacturer shall furnish the inspector daily with carbon determinations of each heat, and a complete chemical analysis every 24 hours, representing the average of the other elements contained in the steel.

No. 2 Rails.—Rails which possess any physical defects or for any other cause are not suitable for first quality shall be considered No. 2 rails, to be applied against contract to an amount not exceeding 5 per cent. and at a reduction in price of 5 per cent. from that agreed upon for first-quality rails.

The specification was very short, as all American specifications were, and very precise; and it simply stated the chemical composition. There the proportion of carbon for rails of 80 lbs. to 100 lbs. was between 0·45 per cent. and 0·55 per cent. Specifications in Great Britain gave the margin of carbon as 0·45 per cent. to 0·50 per cent.; so that the practice in the United States regarding carbon was not very different from the English. The only noticeable point in the American as compared with the British specification was in the amount of manganese; that was greater in America than in England. He had never heard of 0·7 per cent. of carbon in America; and his inquiry had reference to negotiations on a large scale. As to the hammer-hardening of rails, which he regarded as the crux of the whole subject, that was, unfortunately, not a new story. Among his curiosities he had found a broken rail which supported exactly the statements of the Author, and illustrated exactly the process which had been described, and shown so beautifully in the photographs of rails which had failed. It was a broken rail which had fractured from the precise cause mentioned by the Author. He desired to show that these minute cross cracks were not such an extraordinarily rare disease; it was one that had been known of, but which, so far as he knew, had only been noticed on rails which were considerably fatigued. That statement embodied an experience which he had had so far as breakages and failures on the Great Western Railway were concerned. It was a matter which his Company looked upon with a certain amount of anxiety, but it did not produce any consternation. They had other samples

Mr. Inglis.

where the fractures visibly ended at a very shallow depth, and to know the reason of that he would like to hear Sir William Roberts-Austen's opinion as to whether these minute cracks might not be due to the difference in the expansion of the materials of the steel after it had been so altered in constitution by the hammering referred to in the Paper. Members knew that that hammering process made steel so hard that it could not be impressed by a tool; and the photographs illustrating Sir William Roberts-Austen's Paper—together with his subsequent remarks and explanations, which he thought fully as interesting as the Paper—clearly showed a total alteration in structure of the rail and the steel. He would like Sir William's opinion as to whether that alteration in structure which was known as hammer-hardening must alter the rate of expansion of the metal. The surface-metal being thus altered while the internal metal was not might be the reason for those cracks occurring. He showed another specimen of a similar crack combined with a locomotive-wheel mark, doubtless starting with the rail either dry, or rubbing the rail and indenting it. That fracture was accompanied by a similar small transverse crack close to the main fracture, and no doubt was associated with it. Whether it was there before this exceptional wear took place on the rail, or whether it was caused by it, he could not say; he only pointed it out as an instance to be considered—that there was the same class of fracture associated with rough usage, such as it received when an engine attempted to start, and the wheel revolved without the engine moving bodily. He desired also to refer to the very valuable observation which the Author seemed to make clear, namely, that a soft rail was fully as liable to this process of deterioration as a hard one, which he thoroughly believed. The number of experiments the Author had made was comparatively small with regard to the evidence in the Paper, but he thought it was a fair inference from the Paper, at p. 155, where the Author stated he found that a pressure of 33·5 tons per square inch showed that a soft rail did not avoid this excessive development of the minute fracture he was describing. That entirely agreed with his own experience. With Mr. Ross, engineers had been seeking a harder and tougher steel. That point pressed on railway engineers chiefly in the matter of fittings, and he had found it necessary to take steps in that direction. He had made extensive enquiries, and had a large quantity of open-hearth steel rails rolled. The Great Western Railway Company many years ago had purchased from a Welsh company a number of ingots of the Siemens-Martin process and rolled rails from them, and they had had no rails which wore so well. This experience gave the lead, Mr. Inglis. and he had a number of rails rolled with Siemens-Martin steel, and precisely to the cross-section or to the standard of the rail which they now used. He had these tested physically and chemically, and also side by side with a number of similar tests on the same rail by the Bessemer process. There was no doubt that by the Siemens-Martin process a harder and tougher and more reliable rail could be obtained. But, unfortunately, the cost was £2 per ton more in England, and that prohibited, except for the matter of fittings, the Siemens-Martin rail for ordinary use. The result of investigations with the open-hearth steel was, on the average, 49·16 tons stress per square inch, with an elongation between points 2 inches apart—which was almost a standard distance—of 13·18 per cent., whereas the similar lot of rails by the Bessemer process gave 43 tons to the square inch, and an elongation of 20 per cent., showing that the open-hearth rails had a less elongation, by the difference between 13 per cent. and 20 per cent. But unless this was an average, it would be of no value; the result, however, were so uniform that they showed the rate of elongation could be depended upon. The experience of his Company had been in accordance with those results, and they were now using them for the parts of the fittings which were more stressed than others. He mentioned that simply to show the direction in which railway companies would be driven, at any rate, beginning with fittings. Very likely manufacturers could also make cheaper rails. With regard to the depth of the rail, he would rather have $\frac{1}{8}$ inch greater width in the top than $\frac{1}{2}$ inch greater depth. As to his reasons for that opinion, he had in his mind a somewhat large case of relaying of rails where the subsoil was soft. It was ballasted thoroughly with a new road, twelve sleepers being set to a 32-foot rail. That road could not be made to settle down into what they regarded as a first-class running road; and after a good deal of investigation he decided to try thirteen sleepers to 32 feet. The thirteenth sleeper had the effect of getting over the difficulty; and he did not hesitate to say that in all cases of soft formation, and in certain cases of curves where they had used thirteen sleepers where previously twelve had been laid the best results had followed. They had been able to reduce the labour, and it only showed that the weakest part in the present permanent way was in the area of sleeper bearing on the formation; and it appeared to him that in a 95-lb. or 100-lb. rail a girder was already obtained sufficiently strong to do what was required. But care was necessary to build on good foundations, and it seemed that the spreading of the area on that was very important. With regard to the width, he had had occasion to take diagrams, and he found in the best class of road that the lateral oscillation was five or six times that which occurred vertically. That only showed that the movement and knocking on the side of the rail was considerably greater than that operating on the top on a good road. In some roads the blows were exceedingly violent, and he thought the Author might add to his *a b c d*, on p. 158 of the Paper, a fifth heading—*e*, taking into account the side oscillations due to horizontal knocks. This subject had been brought under his attention a good deal, and perhaps he had been in an exceptional position to estimate it, because his Company had to deal with longitudinal road. It was known that the individual parts on that type of road were more rigid longitudinally than the individual parts of a cross-sleeper road, although the weakness in a longitudinal road was the want of sufficient tie. As to rail joints, he would only state his opinion that with the increased weight of rail the importance of the joint diminished. It did not vanish, but it was not so acute as it was in the earlier stages when the rails were lighter. He was exceedingly glad to hear Sir Lowthian Bell state his general conclusions with which his own small experience, and that of those who advised him, entirely agreed, namely, that there was a capriciousness about the behaviour of steel—at any rate about its failures—which was not disheartening, but which, with the prospect of further research, such as that shown in the two Papers, particularly Sir William Roberts-Austen's, gave hope that out of the chaos order would yet prevail. He could not help thinking that by a further Paper, showing the effects of alloys individually, or showing that the finer the grain of steel the more reliable it was, a good deal would be done towards a simple inspection sufficing to judge of the quality. He noticed that the Author spoke disparagingly of the drop test. He admired the Author's accurate scientific observations, but having personally to buy large quantities of rails and test them, he would not like to forego the privilege of the drop test, and he thought that if the Author asked any locomotive engineers to forego that test in the matter of their tires, for instance, he would have to go a long way before he got one to say "Yes." The rail failed from a series of blows, and he could quite understand an incipient flaw standing a certain amount of static pressure, but with a sudden application or jerk it would be revealed. Mr. Inglis.

Mr. HARRY FOOTNER felt, in common with many other engineers, that the profession was much indebted to Mr. David Kirkaldy for what he had done some years ago in relieving them from that delusive security of famous brands by a rational system of testing by which the quality of steel or iron was proved independently of Mr. Footner.

Mr. Footner. where it came from. He was glad that his son was applying himself to the investigation of the condition of steel rails, in which it was stated that induced cracks were developed by the action of the wheels, resulting ultimately in fracture. He was able, however, to testify that in practice an extremely small number of rails broke in the road, that he did not remember any mishap on the London and North-Western Railway which was due to a broken rail. During the last 12 years he had recorded certain particulars of every case that had occurred. From every rail broken two bars had been cut and tested transversely. In some cases there had been tensile tests of the material as well. At least 40 per cent. of the fractures were not the result of induced cracks, because in these the flaws were found only in the web and in the foot of the rail, the head appearing to be quite sound. The total number broken was 388, and assuming the average life of a rail to be 20 years, and there were 7,400 miles of single rail in the running lines of the London and North-Western Railway, that would give an average of 1 rail in 2,000 breaking in the road. In trying to ascertain the primary cause of the breakages he had noted and classified the rails according to their position and conditions of service in the track. As regards the seasons they broke as follows:—29 per cent. in the spring, 16 per cent. in summer, 22 per cent. in autumn, and 33 per cent. in winter. As regards their position in curves and tangents, 27 per cent. broke in curves from 5 to 60 chains radius, 24 per cent. in curves of radii exceeding 60 chains and 49 per cent. in straight lines. Of those broken in curves nearly two-thirds were in the lower rail. As regards the position of the fractures—

11 per cent. subjected to brake action 26 ,, ,, not subjected to brake action	broke between the fish-plates within 10 inches of the end of the rail.
36 per cent. subjected to brake action 27 ,, ,, not subjected to brake action	broke elsewhere at various parts of the rail.

Of the fractures between the fish-plates 85 per cent. were at the end at which the wheels came on them, and 15 per cent. at the end at which the wheels left them. Of the fractures not between the fish-plates 30 per cent. occurred at a chair, and 70 per cent. between the chairs. As regards the weights at which 84-lb. bull-headed rails broke—

10	per cent.	broke between	84 lbs.	and	80 lbs.
31	,,	,,	80	,,	75 ,,
28	,,	,,	75	,,	70 ,,
16	,,	,,	70	,,	65 ,,
11	,,	,,	65	,,	60 ,,
4	,,	below	60 lbs.		

As regards the weights of traffic carried by the rails before breaking— Mr. Footner.

3 per cent.	broke after carrying	between	$\frac{1}{4}$ million	and	$2\frac{1}{2}$ million	tons.
35	„	„	$2\frac{1}{2}$ „	„	25 „	„
45	„	„	25 „	„	50 „	„
17	„	„	50 „	„	100 „	„

The life of the broken rails in the line was—

3 per cent.	between	0 years	and	5 years.
23 „	„	5 „	„	10 „
36 „	„	10 „	„	15 „
24 „	„	15 „	„	20 „
4 „	over	20 years.		
10 „	age unknown.			

From the foregoing particulars it was seen that neither the age nor the weight of the rail, nor the amount of traffic, nor the influence of the seasons, nor the position in curves and tangents, nor the action of brakes or trains starting, took any such leading part as to justify the assumption that any one of them determined the fractures. That more broke at the joint than elsewhere without taking into account manufacturing defects at the ends, it might be anticipated that many would break between the fish-plates owing to the tensile stress in the web caused by the fish-plate bolts tending to force the head and foot of the rail apart assisted by the leverage of the fish-plates and concussions of the wheel passing from one rail to the next. The test bars cut from broken rails of the bull-head section supported at the ends and broken by a central load gave the most diverse results; but generally speaking old rails often failed with greatly reduced loads and deflection when the head was placed in tension, and this weakness was confirmed by the direct tensile tests of the material taken from the head and foot of the rail respectively. Similar tests from new rails of this section pointed to the existence occasionally of some difference in this respect, but in a far less degree, and he would like to know whether the unequal rate of cooling of an unsymmetrical section would sufficiently account for it. He was prepared to believe that the concussions a rail was subjected to, when under rapid alternations of stress by the blows of flattened wheel tires, had a damaging effect upon the running surface and the parts of the head adjacent, and these might determine the moment of fracture of an imperfect rail; but he was of opinion that the primary causes of rail fracture did not have their origin in the treatment of the rail in the track, and that engineers must chiefly look to an alteration in the ores used in making the steel,

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Mr. Footner. and to an improved manipulation in every stage of manufacture for a greater immunity from these breakages, the practical question was whether an improvement could be obtained without adding too much to the cost of the rail. Mr. Walter Katte, the chief engineer of the New York Central Railway, had used rails with 0·5 to 0·6 per cent. of carbon with 1·1 and 1·3 per cent. of manganese for an 80-lb. rail, and had informed him that with phosphorus not exceeding 0·06 per cent., and sulphur 0·069 per cent., great toughness and elasticity had been obtained, with results satisfactory in the highest degree, for some years past. He hoped Mr. Kirkaldy would have the opportunity of continuing his tests, which were valuable from their extreme accuracy.

Mr. Deacon Mr. G. F. DEACON remarked that, as compared with railway rails, the question of tramway rails was less important at the present time; but mechanical traction was destined, he thought, to have the effect of reducing the discrepancy. Certain experience of the behaviour of tramway rails had an important bearing upon railway practice. Twenty-two years ago he had occasion to relay the Liverpool tramways, which were among the first urban tramways laid in England. After a few years of the working of the American lines, which had previously been laid down, the Corporation obtained powers to take them over and to reconstruct the permanent ways. Naturally he gave a good deal of attention to the subject before coming to a decision, and when he did come to a decision, it was to lay the lines at the same time as the renewal of the pavements, and to do so upon a concrete foundation; but to place between the concrete foundation and the rails an elastic cushion of timber, that cushion not to be loosely laid like an ordinary sleeper but to be jammed, as it were, between the rails and the concrete foundation by fastenings, which passed through the cushion and concrete and held the rails down to the under side of the concrete foundation. Except as consulting engineer, he only acted for that department for some 3 years after that, and he had therefore had nothing to do with the constructive work that immediately followed. But what he did at the time was to relay the whole of the Inner Circle, as it was called. That Inner Circle was completed in the year 1877—22 years ago. From the Inner Circle there were radial lines, and the whole of the traffic of those radial lines passed nearly all the way round the Inner Circle; some of it passed the whole distance round, and all of it most of the distance round, so that the traffic on the Inner Circle was evidently very much greater than that on any of the other lines. Two years ago he was called in again to look into

Mr. Deacon.

the matter and explain the reason why the tramways of the Inner Circle had never been taken up, while all the others subsequently laid had been taken up and renewed more than once. He would refer only to two streets, for the reason that the traffic was not exactly the same on the whole of the Inner Circle, nor was it exactly the same on all the branch lines. The two streets were Lord Street—of the Inner Circle non-rigid system—and Scotland Road of the branch lines, rigid system. The general principle of the rigid system portion was the same as that of the non-rigid system, except that a cast-iron sleeper was substituted for the timber cushion. Measured in terms of weight of traffic against quantity of steel worn away, the wear in the case of the Lord Street, non-rigid rails, was only 35 per cent. of that of the Scotland Road rigid rails. That was the leading fact, and it had been noticed by others who were not engineers. He confessed he was so surprised at that result—not at the fact of a result of the kind, but at the intensity of it—that he sought for an explanation beyond the mere change in the elastic condition of the rails and sleepers. He first investigated the difference of the ordinary vehicular traffic, which was not included in the weight of tramway traffic by which the above percentage had been obtained. It was found that there was just about four times the vehicular traffic on the Inner Circle non-rigid, as on the Scotland Road rigid lines, during the lives of the rails respectively. He then investigated the frequency of the use of the brake, and in Lord Street (non-rigid) the brake was used three times as frequently during the lives of the rails respectively as in Scotland Road (rigid). The last speaker had, 13 years ago, pointed out, he believed for the first time, that corrosion was affected very largely by wear.[1] Rust on the surface of a rail, like that on the interior of water-pipes and other apparatus, constituted a more or less protective coating against further rust; but if traffic passed frequently over a rusting surface, the rust was almost continuously worn off, and the coating was never allowed to become really protective. There were two possible causes of difference of deterioration by rusting in the two places; one was the quantity of manure, and the other was the impurity of the atmosphere. But the quantity of manure deposited on the rails of the Inner Circle (non-rigid) was greatly in excess of that deposited on those of Scotland Road (rigid). In point of atmospheric effect he came to the conclusion that there could be no appreciable difference. Having thus settled to his own satisfaction

[1] Minutes of Proceedings Inst. C.E., vol. lxxxiv. p. 438.

Mr. Deacon. that all the external causes of wear were in favour of the longevity of the rigid system which by comparison wore so badly, he investigated the mechanical properties of the rail itself in the two cases, and then the chemical properties. In the first place, with regard to the mechanical properties: a number of pieces of different rails were sent to Professor Unwin, and he tested them for hardness and for elasticity and other mechanical properties.

The following Table summarized the results :—

—	Hardness Number.	Elastic Limit.	Tenacity.	Elongation in 8 inches.
		Tons per Sq. In.	Tons per Sq. In.	Per cent.
Inner Circle, Lord Street (non-rigid) .	204·5	22·7	37·9	19·5
Branch line, Scotland Road (rigid) . .	218·3	24·3	43·6	14·2

Even the hardness, therefore, was a little in favour of the rigid lines, but the difference was small. The chemical tests also showed that there was practically no difference between the steel in the rigid and the non-rigid constructions. The results were as follows :—

—	Lord Street (non-rigid).	Branch Line, Scotland Road (rigid).
	Per cent.	Per cent.
Carbon	0·442	0·428
Silicon	0·056	0·064
Phosphorus	0·054	0·040
Manganese	0·672	0·600
Sulphur	Under 0·080	Under 0·080
Copper	Bare trace	Bare trace

So that all the conditions that it had occurred to him to investigate for the purpose of showing that comparative elasticity was not the only explanation of the difference, supported the view that it was the only explanation. They either gave practically identical results, or were in favour of the longevity of the rails which had been laid on the comparatively rigid system, leaving the conclusion that the comparatively rigid system gave an efficiency measured in terms of intensity of load and of wear of the rail less than 35 per cent. of that of the non-rigid system. This result was certainly startling, but after taking great pains to discover any other cause than the difference in point of rigidity of the two cases, he had been forced to the conclusion that the great durability of the Inner Circle, as compared with that of the branch lines was solely due to its less rigid though firm construction. Mr. Deacon.

Sir FREDERICK BRAMWELL, Bart., wished to state two difficulties that he felt. In the year 1853 he was in the United States and saw one piece of railway in Virginia of the old construction—flat bar iron laid upon a continuous bearing, the bar held down by spikes, and having a bird-mouth joint at the ends. He saw the carriages had bars fixed to them for the purpose of preventing the ends of the rails from being forced up through the seats and so injuring the passengers. This precaution was needed because the result of rolling of the wheels over these bars of iron was—instead of curving them downwards, as he should have thought would have happened—to cause them to curve upwards, and thus the ends of the bars rose; with the result that if the wheel, instead of going over the curved up end and setting it down, went under it and lifted it, an accident took place. That was effect No. 1 of rolling the surface. Then came No. 2. When he was an apprentice it was customary to make metallic pistons by turning the rings to the size of the cylinder, then cutting them open in one place, and then hammering the inside of the iron with a hand hammer, thereby expanding the ring outwards, as he thought it ought to expand, the effect being that the iron inside was elongated and the thing expanded. In the case of the rail the iron appeared to be shortened and the thing curled upwards. He could not comprehend those two things. If he might be allowed to refer to a somewhat analogous case of very different material for a different purpose, he would say that when a cook wished to decorate a knuckle of ham with one of those curly paper things which were often seen, those papers were produced by drawing them over the blade of a knife. Any member could try the experiment, and it was known as a result that the paper would curl towards the blade over which it was drawn like the American rail curling towards the wheel which went over it. He did not know why; he merely stated those facts. He could quite understand that, if for some reason or another, the rail wished to curl upwards as it did in old days when it was a flat bar, and it was made in these days into a girder of 6 inches deep, so that it Sir Frederick Bramwell.

Sir Frederick Bramwell. could not curl upwards, the result must be to produce the minute transverse cracks. But he did not know why it wanted to curl upwards.

Professor Arnold. Professor J. O. Arnold had read Mr. Kirkaldy's Paper with much interest and admiration, and that of Sir William Roberts-Austen with a little surprise. In December, 1895, he had the honour of reading before the Institution a Paper,[1] in which was announced for the first time the determination of the saturation-point at 0·9 per cent. of carbon, and which traced up very clearly the relation of ferrite and pearlite; and not only that, but during the discussion he pointed out the lowering of the saturation-point by manganese; and at the end of the meeting, Mr. Andrews, who had applied to steel rails the principles privately enunciated to him some time before showed on the screen a dozen sections of steel rails resembling those which had been shown. He thought therefore that it was hardly accurate to say that the subject had not been brought before the notice of the Institution. In making micrographic analyses of a steel rail it was necessary to take the history of the rail into consideration from the time it left the Bessemer converter. If a rail was cast in a 16-inch ingot and the metal was very hot, there was certain to be more or less liquation; that was, the top of the ingot would be higher in carbon, in sulphur, and in phosphorus, than the bottom, and the centre would tend to be higher in those elements than the outside. So that in investigating a steel rail to make micro-sections of it, it was necessary to explore the rail very thoroughly in the manner which he (Mr. Ross) had done chemically, not only along the length but through the whole section at each end, in order to get its chemical analyses and its micrographic analyses in different parts. He might mention the case of a steel tire he had examined some time ago in which two adjacent test-pieces had been tested. One gave an elongation of 9 per cent., and the other of 31 per cent., pieces lying adjacent to each other in the same tire. On investigation it was found that, even in that small tire, a large difference in composition and in microscopic structure existed. He thought the piece which gave the good elongation contained 0·03 per cent. of sulphur, while the sulphur in the unductile piece was about 0·12, and very similar results were shown in Mr. Ross's analytical diagrams of his rail. The sections shown by Sir William Roberts-Austen were rather different from those he had examined—a fact possibly due to

[1] Minutes of Proceedings Inst. C.E., vol. cxxiii. p. 127.

Professor Arnold.

the difference in the method of preparation. He fancied that the magnification selected by Sir William Roberts-Austen, 140 diameters, was a little unfortunate. It was too large to enable the section to give a good wide view of the distribution of the iron and steel or otherwise of the ferrite and pearlite, whilst the magnification was not sufficiently large to give a good idea of the junctions between the ferrite and the pearlite. He had looked at the sections very closely, and perhaps Sir William Roberts-Austen would explain, why the whole of the ferrite in those sections seemed to be amorphous. All sections that he had made of steel rails presented crystallization in the ferrite itself, and the joints of such ferrite of course formed an important part of the strength of the material. He also noticed another peculiar feature of those sections, namely, the entire absence of sulphide of iron, although it was stated that the sulphur ran from 0·04 to 0·09. In his examinations of steel rails containing sulphur as high as 0·09, at any rate by his method of preparation, he could trace the sulphur distinctly dotted throughout the mass quite as well as the pearlite and ferrite; and as sulphur was likely to be an element of the greatest importance in the investigations about to be made on steel rails, it seemed to him a method of preparation should be used which showed it clearly. He was quite unable to detect its presence in any of the micrographs which had been shown. With reference to Mr. Kirkaldy's Paper he agreed with most of his conclusions; the Author had shown very clearly a remarkable effect. From the point of view of the metallurgist there remained to find out the cause, and the evidence on every hand was so conflicting that there was evidently a very difficult and long research to be made before metallurgists could explain the remarkable vagaries of steel rails. Increased hardness, he thought, was a little apt to frighten some railway engineers; but he should explain, knowing Mr. Kirkaldy's views, that that hardness was not necessarily carbon hardness. For instance, he did not think Mr. Kirkaldy would advocate an advance of the carbon to 0·6 or 0·7 per cent. He really meant to maintain a sufficient quantity of ferrite (and it should be remembered that the ferrite would disappear at 0·7, with 1 per cent. of manganese), to retain in the micro-structure a sufficient quantity of ferrite to give ductility. But what he really suggested was to harden the matrix of ferrite with some element like nickel, manganese or chromium, as suggested by Mr. Price-Williams. He thought it very likely that there was a good deal to be said for that view. He agreed with the speaker who asked Mr. Kirkaldy not to speak

Professor Arnold. quite so hardly of the drop-test. He did not think if a rail was balanced carefully between centres, and a definite amount in foot-lbs. was dropped upon it, that it could be called a crude test. What it did was certainly to give the steel a test from a vibratory point of view, a vibration along the steel which no other class of testing could do. The hammer hardness which had been spoken of in the rails, it should be remembered, was only skin deep; it was only really a skin on the surface of the rail. All railway engineers were aware that there was a reciprocal skin upon the face of a tire. When a tire was turned up, it was just as hard as the surface of the rail. In fact it was very difficult to find turning-tools which would face the skin of the tire, it was so intensely hard. He thought the hardness, as tested mineralogically, was somewhere about $7\frac{1}{2}$ on the mineral scale, which was exceedingly hard. Mr. Kirkaldy had mentioned induced flaws; he thought he had shown that in some cases these flaws were not produced, while in others they were produced and apparently in the same composition. He should rather like to substitute the term "potential flaws," because if the analysis and structure of the steel were correct, he did not think that those flaws should develop. Anyhow, it struck him that Mr. Kirkaldy's results had been made so carefully, and contained matters of so much interest, that some time ago when he met him he volunteered to complete his remarkable mechanical observations with a careful set of chemical and micrographic results. When these were finished, he had no doubt that the results would be laid before the Institution, and then the members would have a complete series of results, mechanical, chemical and micrographical, on rails of known history.

Mr. Robertson. Mr. F. E. ROBERTSON noticed that, in the first Paper, the Author used the term stress and load as synonymous. He could hardly call the load which deflected a beam the stress in the beam; and that cast a doubt throughout the Paper as to whether the results meant the stress on the ultimate fibres of the rail, or the load on the rail which developed those stresses. The Tables would have been more easily read if they had been arranged in the order of hardness of the rail or endurance. It seemed *a priori* not unreasonable to suppose that a harder steel would resist better the local action of the wheels than a softer steel, and so escape the incipient flaws which ultimately led to fracture. But although he held that opinion, it was one for which, so far as he knew, there was no absolute proof. American practice tended in the direction of harder rails. A previous speaker had doubted whether

Americans used such hard rails as 0·7 per cent. of carbon. The following Table showed the specification of the New York Central Railway by the well-known railway chemist, Dudley, and W. Katté, the Chief Engineer:— Mr. Robertson.

Weight of Rail, Lbs. per Yard.	65	70	75	80	100
Carbon . . per cent.	0·45–0·55	0·47–0·57	0·50–0·60	0·55–0·65	0·65–0·70
Manganese . „	1·05–1·25		1·10–1·30		1·2–1·4
Silicon	From 0·15 per cent. to 0·20 per cent.				
Sulphur	0·069 per cent. maximum.				
Phosphorus	0·06 „ maximum.				

He inclined to the view of American engineers in thinking that possibly harder rails might be used, but the analogy of wire-drawing seemed to him to be rather against that. Was it not the fact that a harder billet would require annealing after passing through the dies more than a soft one, and would not the action of the dies be very much the same principle as the hammering of the wheels on a rail? He could not find also that the Author's facts quite supported his conclusions. For instance, in the first series there was a rail of 44½-ton steel which broke in the road, while its neighbours—which only averaged 36 tons tensile strength, and some were as low as 34—did not break. If that first rail was the rail alluded to in the first column of Table I, p. 184, it was possible that a high phosphorus and other impurities might account for its being brittle. Then in the second series a 36-ton steel was singled out for special commendation, but a 36-ton rail was not a very hard one; it was a fair medium rail. In the third series the 60-ton steel behaved admirably, but then there were two other hard rails which broke in the road. The analysis of those rails might throw some light on the difference in the behaviour of them. In the remaining series, the tensile tests given were too few and too uniform to point to any very definite conclusion. But he had some tests of rails which would help to give some evidence on the subject. There were some rails that were 30 years in the main line of the Taff Vale Railway, which had a very heavy traffic. Those rails were taken up because heavier rails were required. They had worn so admirably that it was thought desirable to make some investigation into their qualities. Therefore six pieces were taken and tensile tests and

Mr. Robertson. analyses were made from different parts of the rails. They were very uniform, and the average figures, which he would mention, would represent fairly any one of the tests. The rails were 76-lb. rails, and were laid in 1866 and taken up in 1896, weighing 71 lbs. a yard. The tensile strength gave 35½ tons; the elongation was 20 per cent., and the contraction of area 40 per cent. on 10-inch test pieces. The average analysis was:—carbon, 0·378 per cent.; silicon, 0·044 per cent.; sulphur, 0·047 per cent.; phosphorus, 0·056 per cent.; arsenic, 0·031 per cent.; manganese, 0·34 per cent. The microscopic examination of the heads showed no sign of flaws. One could not reasonably expect better service from rails than those gave, but they could scarcely be called hard rails—they were good medium rails. He noticed also the rail shown by Sir William Roberts-Austen, in Fig. 6, and spoken of as a very excellent rail, could not be called a very hard rail, for with full amount of phosphorus its tensile strength could scarcely have been above 38 tons. Now all the good rails fell within the limits of the specification his firm were in the habit of using, which was carbon 0·3 to 0·45 per cent., and other impurities not to exceed 0·06 per cent. for any one of them. If that specification gave safe rails, and the rails wore as well as the figures seemed to indicate, was it worth while taking chance and getting harder rails for possibly a better wear? Would the harder rails wear any better? He had two analyses of rails that came in that day, and they were very much the same as the Taff Vale rails. One came from the North and one from Wales. With regard to the rail from Wales, the analysis was, carbon 0·367 per cent., silicon 0·020 per cent., sulphur 0·050 per cent., phosphorus 0·035 per cent., manganese 0·565 per cent., arsenic 0·028 per cent. The rail from the North had, carbon 0·370 per cent., silicon 0·034 per cent., sulphur 0·057 per cent., phosphorus 0·031 per cent., manganese 0·456 per cent., arsenic 0·009 per cent. Those were very fair average rails, and such rails seemed to wear very well. After 30 years' experience of using rails in India, where the traffic, of course, was not so intense as it was in England, it seemed to him that the most practical point to avoid breakages was to leave plenty of crop end. He thought that more than half, probably 75 per cent., of the broken rails that had come under his observation had been due to mechanical flaws in the rolling. In any case, in India, at least, broken rails did not cut a large figure, for during the years he was chief engineer of the East Indian Railway the percentage of broken rails was 1 in 495,000 per annum, the average age of the rails that broke being 11 years. It was to be hoped that the

Mr. Robertson.

Royal Commission now sitting would afford some useful information on that very complex subject, because when even the tensile strength and the chemistry were known, all was not known about the rails. It was certain that the treatment during rolling profoundly modified the product, and it might be possible that even the distribution of the work had some effect—that a certain number of trains might not have the same effect if they passed in one day as if they took ten days to pass; there might be a higher ratio of wear if the traffic was more intense. Then, again, to collect data from worn rails was not so very simple. Just lately he had a case before him where a road in India, laid with narrow round-top rails, was being re-laid with flat-top wide rails. The tires grooved by the narrow rails were running, of course, on the edges of the new ones, and the wear was so intense that flakes of steel were worn off the new rails just like wood shavings, some nearly an inch long. Certainly rails which had been subjected to that treatment could not be expected to give as good results as rails which had normal treatment from a tire that fitted them. Sir William Roberts-Austen's Paper was very interesting, and it was to be hoped that he would continue the study, and place in the hands of engineers a more powerful weapon for the search for that much desired but difficult matter to attain—to know what was the best rail.

Mr. Preece.

Mr. W. H. PREECE, C.B., President, said that, before he asked Mr. Andrews to continue the discussion, he thought it right the members should know that, as an exception in this case, slides would be allowed to be shown to illustrate the remarks that were made. As a rule, in discussions, the Institution did not permit slides to be used, because they were ephemeral, and attention during discussion could not be called to them and to debatable points so illustrated; but in this particular instance, owing to the fact that the work to be shown was so delicate, and of such a character as to render its embodiment in ordinary diagrams impossible, the first three speakers would be permitted to illustrate their remarks with lantern-slides.

Mr. Andrews.

Mr. THOMAS ANDREWS observed that one of the great points in connection with rails in the future was whether they were to be low-carbon and low-manganese rails, medium-carbon and medium-manganese rails, or high-carbon and high-manganese rails. As consulting metallurgical expert to the Great Northern and other chief British railway companies, opportunities had been afforded him of carefully investigating that most important question over a number of years, experimenting upon typical samples from many

Mr. Andrews. thousands of tons of rails, not purposely selected, and in connection with no theory, and he desired to show several instances of the advantage of the chemical analysis of steel rails and of the microscopic investigation thereof. The first slide exhibited a type of the high-carbon rail containing also micro-flaws which could be observed scattered about. The high-carbon rail was given to segregation of the carbon contents, and segregated areas were scattered throughout the mass of the rail in which considerable liability to fracture was present. The white portions were areas of ferrite, and the grey portions consisted of carbide of iron. There was an unevenness of texture in high-carbon rails which was detrimental to the life of the rail. The next slide showed the wearing face of a rail of the medium-carbon and medium-manganese type, a low-carbon and a low-manganese rail being one which in carbon contents was below 0·35 per cent. and the manganese contents below 0·7 per cent. The next grade of rails he should class in the following manner:—Medium carbon and medium manganese, speaking roughly, were rails ranging from 0·35 per cent. to 0·42 per cent. of carbon and the manganese from 0·7 per cent. to 0·85 per cent.; beyond 0·42 per cent. of carbon, and beyond 0·85 per cent. of manganese, he preferred to class them as a high-carbon and high-manganese series of rails. Most of the rails would come under one or other of those subdivisions. The one shown on the slide was a low-carbon and low-manganese rail, and it had worn 24 years in the main-line service on the Great Central, or old Manchester, Sheffield and Lincolnshire Railway. There was no deterioration detected beyond the grinding down of the face of the rail. There were no transverse cracks. The wear would not be more than about 0·3 lbs. per yard per annum over the long life of 24 years. The rail was simply taken out because of its actual grinding down on the face; no defect was perceived in it. The next slide exhibited the micro-structure of the rail which he had just shown, with a magnification of 300 diameters. It would be seen that there was an adjustable sort of arrangement between the carbide areas and the white ferrite, an even interlocking structure, so that there were no carbide areas running into each other as in the high-carbon case. It was an interlocking structure as between the ferrite and the areas of pearlite, and that was the one which was most likely to endure the wear and tear of railway work. The percentage of carbon in the rail was about 0·25 and the manganese 0·43. The next slide showed a rail from the Great Northern Railway which had worn for 23 years, the carbon

Mr. Andrews. contents of the rail being 0·34 per cent. and the manganese 0·478 per cent. It was an old rail, and had worn exceedingly well, with no indication of deterioration perceptible either microscopically or on the rail face beyond the few slight longitudinal flaws which could be seen running the length of the rail. Another slide represented the micro-structure of the preceding rail. The same interlocking structure could be seen as between the ferrite and carbide areas. When the carbon increased, those areas tended to run into each other and formed lines of weakness across the face of the rail, leading, under the influence of stress, to fine transverse cracks. The next slide showed the face of a rail after 18 years' wear, a medium-carbon and medium-manganese rail containing carbon 0·36, manganese 0·77 per cent. The next slide exhibited the micro-structure of the rail showing the fairly even interlocking structure as between the ferrite and the pearlite. In the next slide he brought before the Institution a diagram of ten old rails, the time of life varying from 22, 24, 23, 25 years to 17, 18 and 19, etc., years. One column gave the average loss in weight in pounds per yard per annum. It also showed the chemical analysis. The average carbon of the set was 0·40 per cent., which had worn an average life of 21 years, and the average loss in pounds per yard per annum was 0·324. The manganese was 0·51 per cent., the tonnage was 40 per square inch, the elongation 25·15 per cent. in 2 inches, and the reduction of area 37·65 per cent. He next introduced to the members the good results that were obtained in rails of medium carbon and medium manganese of the following composition. The first slide showed the micro-structure of a rail; carbon 0·38 per cent., silicon 0·04 per cent., low phosphorus and low sulphur, and manganese 0·67 per cent. The same interlocking structure was seen, about an even proportion of the mass being composed of pearlite and the other part of ferrite. The next slide showed another type of the same class of rail; 0·38 per cent. of combined carbon; 0·80 per cent. of manganese, with the impurities as low as practicable. The structure was similar to that shown in the preceding slide. The slide which followed showed the structure of rails of high carbon and high manganese and the inferior physical results yielded by them. The carbon was 0·45 per cent. and the manganese 1·21 per cent. The structure was altered considerably by the excess of manganese; the crystalline areas were enlarged and ran together. The presence of manganese beyond 0·85 per cent. appeared, from a number of observations he had made, to throw the carbon areas very much

Mr. Andrews. together and cause considerable lines of weakness along the pearlite areas. There was not that evenness in the interlocking structure that was shown in the rails previously shown on the screen. The sulphur and phosphorus would be about 0·06 per cent. There were no excessive impurities in the rails. Another slide also showed the type of high-carbon and high-manganese rails, and exhibited the uneven distorted kind of crystalline structure. The rails were new rails. The next slide was a Table which contained the results of the chemical analyses and physical tests of a very large number of high-carbon and high-manganese rails, the average being 0·451 per cent. of carbon and manganese 0·993 per cent. The maximum stress was 43·3 tons per square inch, and the elongation only 14·22 per cent. He wanted to draw especial attention to the Table because the tests were taken over a quantity of something like 50,000 tons of rails to show the effect of more or less carbon and manganese. The next slide exhibited results obtained with medium-carbon and medium-manganese rails. The carbon was about 0·39 per cent. and the manganese 0·78 per cent., the tonnage 39·37 tons per square inch, and the elongation 22·6 per cent., so that the reduction of only about 0·2 per cent. of manganese and 0·06 per cent. of carbon from the former case had increased the elongation to 22·6 per cent. That, he thought, was very conclusive evidence that the physical properties of steel rails were very materially affected and reduced as regarded elongation and contraction of area by the addition of manganese beyond 0·85 per cent. and carbon 0·43 per cent. as a maximum. The next slide showed a rail typical of the effects of metalloid impurities. It was also a high-carbon rail with a considerable percentage of sulphur. The effect of that was to induce minute transverse cracks which could be seen on the face of the rail. They would be not more than perhaps $\frac{1}{32}$ inch apart, but he had counted on a rail face about 14 inches in length no less than 188 of those transverse cracks, any one of which might produce the destruction of the rail under the impact of its ordinary wear. Another slide showed the face of a rail in which there was sulphur not exceeding in one part of the rail 0·09, but in other parts of the rail the sulphur had gone up to as high as 0·21. The effect of that had been to cause a number of minute transverse cracks across the rail, which led to the fracture of the rail after a comparatively short life. The last two slides were typical of the evil effects of having sulphur beyond 0·06 per cent. In some cases the physical tests were inadequate to find out the causes of fracture, but the chemical and microscopical tests combined generally showed the

Mr. Andrews.

cause of the failure of a rail. Medium-carbon and medium-manganese rails gave in the mass fairly good results, with elongation about 22 per cent. and tonnage of about 39 tons to 40 tons. Several parts of a fractured rail were tested physically, but nothing could be found out from the physical tests about the cause of the fracture. The chemical test at once showed it. He wanted now to point out the evil effects of sulphur, and the way it manifested its presence at a high magnification in rail section. He exhibited a slide showing a high-sulphur rail which broke after 3 years' wear, and the sulphur was found as sulphide of iron segregated among the crystalline particles of the steel in the manner shown. There was no proper metallic cohesion in the rail. The fracture once starting under vibration would easily run along in that direction. The proportion of sulphur would be about 0·09. The next slide showed a length of the wearing face with a transverse weakness. There was no effectual metallic cohesion transversely. He did not know that he had anything further to add, except to say that he hoped before long to present to the Institution a more detailed account of his prolonged investigations, and he should be able then to go more fully into the matter than he was able to do in a discussion like the present. He had brought the slides forward with a hope that they might help to throw a little light upon the important question of the loss by deterioration in steel rails, and assist engineers to predicate a safe specification for the future that would prevent any calamitous results arising from defects, either chemical or physical, in steel rails. He could not agree that the use of nitric acid for etching steel was not to be recommended, because in his own experience, with suitable dilution according to the nature of the steel or iron to be etched, nitric acid yielded equal and even better results than the method referred to in the Paper. The etching method employed was, however, simply one of choice on the part of the operator. Dr. H. Clifton Sorby, F.R.S., the founder of the science of micro-metallurgy, had used the nitric acid etching method most successfully, and Professor Arnold and others had obtained excellent results with this process. Useful information might be afforded by the microscopic examination of steel rails at a magnification of 100 and 150 diameters; but it was desirable, in order to fully grasp the nature of the crystalline structure, to use a magnification of about 300 diameters, and in some cases even much higher. He had frequently pointed out[1]

[1] *Engineering*, 1897 and 1898; also in reports to various railway companies.

Mr. Andrews. that the "interlocking" structure, as between the ferrite and carbide areas, or pearlite, was the most suitable micro-structure to ensure durability and safety in steel rails.

Mr. Jenkin. Mr. C. Frewen Jenkin exhibited a series of photographs which he had prepared with the express object of showing the effects of different methods of polishing. The photographs were all taken from the same piece of steel, which was a piece of specially pure 0·53 per cent. carbon steel, kindly given to him by Professor Arnold. He used three methods of polishing. The first was that recommended by Professor Arnold, namely, polishing on kid skin, dry, dusted over with a little rouge. That had the effect of colouring the ferrite a light red and leaving the carbide with a bright polish. The second method was the Osmond method, used by Sir William Roberts-Austen, polishing on cloth or parchment wetted with water or a solution of liquorice. The result of that form of polishing was to wear down the soft ferrite, leaving the carbide standing out in relief. The third and most frequent method was etching in dilute nitric acid. That had rather a complicated effect, a sort of electrolytic effect, whereby a black hydro-carbon was deposited round the edges, forming a picture in black paint surrounding the actual structure in the steel. The first photograph, Fig. 22, Plate 4, was multiplied 400 diameters. The white lines showed the polished carbide, the whole areas covered with the white lines being the carbide areas referred to by the last speaker. A part of the last multiplied 600 diameters was shown in Fig. 23. The dark portion was that part which was tinted by the rouge. The same steel polished by the Osmond method was illustrated in Figs. 24 and 25. The whole of the area was of course bright steel, and it was somewhat difficult to photograph, as there was no contrast in the colours, but the ribs of the hard carbide would be seen standing out in relief on the worn ferrite. The effects of etching in nitric acid were shown in Fig. 26. That method gave the strongest contrast, and therefore was the easiest to photograph. But what was actually seen was, not the steel itself, but a deposit of hydro-carbon on the surface of the steel. It was somewhat important to observe the difference in what was being actually seen in the three cases. By the Osmond method nothing but the steel itself was seen; whereas by the other methods, in the first was seen rouge, and in the second hydro-carbon. That was the very great advantage of the Osmond method. With regard to the crystalline structure which Professor Arnold said was not shown, it was perfectly well known that all that was necessary to show the crystalline structure was to polish a little longer, and the Osmond method then showed it beautifully. A sulphur flaw multiplied 700 diameters, polished by the Osmond method was shown in Fig. 27. The dark area in the middle and the small pieces scattered about were the actual sulphide of iron. In such cases the Osmond method had a great advantage over Professor Arnold's method. The actual sulphur could be seen, but in Professor Arnold's method the sulphide all fell out, and all that was seen was a hole filled with rouge. Mr. Jenkin.

Mr. J. A. F. Aspinall submitted four photographs which were exhibited, showing presence in locomotive steel tires of the surface cracks that had been referred to during the discussion. The first, Fig. 28, Plate 4, showed the vertical cross section of the tread of a tire from an engine of the Lancashire and Yorkshire Railway, showing depth of surface cracks. The surface of the tread showing cracks running across the tire was illustrated in Fig. 29; and Fig. 30 exhibited flaws produced by slight bending, which had developed from surface cracks on the face of the tire. Fig. 31 showed the polished and etched section of the structure of the metal. Mr. Aspinall.

Mr. T. R. Johnson had, for the past 3 years, been associated with Mr. Andrews in the investigation of the properties of new steel rails; his part of the work having been confined mainly to carrying out the falling-weight tests which Mr. Kirkaldy had somewhat deprecated in the Paper. Notwithstanding the criticism that had been made upon that old-fashioned and somewhat crude weight-test, he thought it was of real value to railway engineers, and he should be exceedingly sorry to see it abandoned for the simple bending stress which had been applied by Mr. Kirkaldy. He should like to refer first to what Mr. Andrews had already said with reference to the composition of steel rails. From the analyses Mr. Ross had supplied, Tables I–III, pp. 184, 185, showing the chemical combination of a rail which was described by Mr. Kirkaldy as probably an ideal rail, it would be noticed that the combined carbon would come in the category of Mr. Andrews' low carbon rails, that the manganese was also exceedingly low, and that the sulphur was moderately low, but the phosphorus exceedingly high. No railmaker at the present day would like to see phosphorus at anything like that percentage. He wanted to bring under the notice of the Institution a second rail, about which he knew something, a rail taken out of the main line of the Great Northern Railway in the year 1896, having been put down in the year 1878, and Mr. T. R. Johnson.

Mr. T. R. Johnson. therefore having borne the heavy traffic of the main line for something like 18 years. The rail had been already referred to by Mr. Andrews. The surface was exceedingly pitted, as if the rail was suffering from smallpox. The chemical analysis of that rail was as follows: The combined carbon in the rail-head, 0·35 per cent.; in the foot, 0·36 per cent.; in the web, 0·37 per cent.; or an average of 0·36 per cent. The silicon in the head, 0·06 per cent.; in the foot, 0·059 per cent.; in the web, 0·07 per cent.; giving an average of 0·06 per cent. The manganese was 0·77 per cent. in the head; 0·75 per cent. in the foot; 0·79 per cent. in the web; with an average of 0·77 per cent. The sulphur was 0·08 per cent. in the head; 0·08 per cent. in the foot; 0·072 per cent. in the web; or an average of 0·077 per cent. The phosphorus was 0·05 per cent. in all three parts of the rail. That, he ventured to think, was almost an ideal rail. It had borne, during the 18 years it had been in the road, traffic of an estimated tonnage of not less than 100 millions. That was certainly within the mark, because it took no account of special trains and only gave the result of booked traffic. Probably he should be nearer the mark if he were to say that it had carried 120 millions of tons. It was taken from the up road on a gradient of 1 in 220 rising with the load, and, therefore, it had been subjected, not to the traffic of empty wagons merely, but to the traffic of full coal wagons coming to London. The amount of wear in lbs. per yard was 5 lbs. during 18 years, and the amount of abrasion was in depth about $\frac{3}{16}$ inch. The physical properties of that rail were very interesting. He had no doubt the members noticed that the interlocking formation, described so well by Mr. Andrews, was present in the rail. In the rail-head the maximum stress was 35·36 tons; the elongation in 2 inches was 31 per cent.; and the reduction of area 43 per cent. In the bottom of the rail the maximum stress was 35·98 tons per square inch, the elongation 32 per cent. in 2 inches, and the reduction of areas was 45·4 per cent. The microscopical examination showed that the carbide of iron areas were evenly and proportionately distributed throughout the white ferrite mass of the steel in the general interlocking formation best calculated to insure resistance both to abrasion and sudden shock. The original weight of the rail was only 80 lbs. per yard. It seemed to him that rails of that class gave something to go upon with reference to the composition of new rails at the present time. Surely railway engineers needed nothing better than something of that sort, and if it was fair to argue from the known to the unknown, in that case, Mr. T. R Johnson.

if they could depend on getting a composition of the kind in new steel rails, surely they had got something which would give a satisfactory wear in the future. It was impossible to say of course what the wear of the present steel rails would be, because there were many questions to be taken into account. He reminded the members that 20 years ago it was the custom to hammer the ingots before rolling took place. In consequence probably of the expense involved that practice was abandoned some years ago, and now the makers were in the habit of cogging rails before rolling them, and in that way, as they said, getting the same amount of mechanical work on to the ingot as was got before by hammering with a steam hammer. At any rate, whether that was so or not, he did think it was one phase which should be borne in mind very clearly. His own opinion very strongly inclined to the belief that one of the reasons why the old rails had worn so exceedingly well in certain cases was because of the fact that a very large amount of mechanical work was got on to the ingots by the process adopted then. It was perfectly true that by the present method of cogging, a large amount of mechanical work was got on to the ingot, but he did not think nearly as much as might be obtained by other means. At any rate, he thought it was important to bear the matter in mind, and it would probably be well to specify that the ingots from which rails of large sections were rolled should be of a certain size so as to ensure as much mechanical work as possible being got upon the rail length before it was cut into the finished lengths. That, of course, could be done by indicating that the ingot was not merely to be lengthened, but that it was to be increased in thickness in both directions, so that as it passed through the cogging mill, it should be more knocked about, the rolls being properly and carefully drafted. In that way he fancied very important results would accrue in connection with new steel rails. The influence of manganese upon the physical properties of steel rails had already been referred to by Mr. Andrews, and he should like to say one word more about it. Looking over a very large number of results, something like 500, which covered perhaps 50,000 tons of rails received during the last 3 years, he noticed—taking the other components of the rails, carbon about 0·40 per cent., silicon at about 0·08 per cent., phosphorus and sulphur at about 0·06 per cent.—that for every 0·1 per cent. that the manganese went up above 0·80 per cent., the elongation decreased by about 3 per cent. in 2 inches. If therefore it was important to obtain satisfactory physical results in connection with new steel rails, he thought that the manganese

Mr. T. R. Johnson. should never get very much above 0·80 per cent., and judging from the experience that one had been able to gather during the long series of experiments to which he had referred, if a medium carbon and medium manganese rail could be obtained, a reliable rail would be secured and he thought also a durable rail.

Mr. Cruttwell. Mr. E. CRUTTWELL desired to refer to the comparative wear of rails when supported in different ways. For instance, whether a rail supported on chairs deteriorated more quickly than a rail laid on longitudinal sleepers, or than a rail laid on cross timber sleepers without chairs. He thought if the Author could give information on that point it would be useful. In his Paper Mr. Kirkaldy advocated a greater depth in the rail. He quite agreed with him in that, and hardly thought that the rails had advanced to such a pitch of perfection as some remarks made by Mr. Inglis would seem to indicate, in which he laid more stress upon the bearing area of the sleepers than on the depth of the rails. He certainly thought that in many rails greater durability would be obtained by increasing the depth, especially in rails that were supported underneath the heads on chairs. Such rails might often be considerably deepened with great advantage and without increasing the weight, because often the web was made thicker than necessary. With flat rails one could not go to such an extreme in the depth, as they had to rely more on the width of their base and the holding power of the spikes to resist the canting due to the blow from the tires on the side of the rail. Rails supported on chairs might, he thought, be improved in that respect, and he thought Mr. Kirkaldy's remarks were very much to the point. With regard to rail joints, it was mentioned by one speaker at the last meeting that it was objectionable to place the sleepers closer together at the rail joints than elsewhere. He did not think that objection could be upheld in every case. The primary object was to make the rail at the joint as strong as between the joints, but in many cases, where the sleepers were more or less far apart, the rail could only be made as strong at the joint as between the joints by considerable expenditure of metal in the fish-plates, and where that was the case he thought there was some excuse in putting the joints of the sleepers closer together. He should much prefer to have a strong joint with unequally spaced sleepers to weak joints with uniformity in spacing of the sleepers. He had placed on the table a joint which he was using in the Orange Free State Government Railways, in which the under sides of

Mr. Cruttwell. the fish-plates were bearing on the sleepers; the sleepers were Australian hardwood imported into the country. He noticed that Mr. Kirkaldy was in favour of steel rails with high tensile strains, but he was not very explicit as to how high he was prepared to go. He should be glad if Mr. Kirkaldy could give his experience on that point. His own practice was to obtain steel with a tensile strain of 40 tons and an elongation of about 20 per cent. in a length of 2 inches, with a reduction of about 30 per cent.

Mr. Beaumont. Mr. W. W. BEAUMONT was gratified that the Paper afforded confirmation of the facts and hypotheses he had the honour of placing before the Institution in 1876.[1] In that Paper he showed how it was that tires on engines and other wheels broke without any apparent cause of fracture, and often through the solid part of the tire rather than through the holes that were made for receiving the bolts by which they were held on the wheels. The remarks which had been made by Sir Roberts-Austen and partly by Mr. Andrews, and also, he thought, by Mr. Johnson, confirmed, to a very great extent, what had been previously supposed to be happening to a rail rolled by the hard steel tires in use at the present time. The stresses arising from the rolling of the rail surface by the wheels had been referred to as being only skin-deep. It was impossible to imagine that the effect on the rail of the rolling would bring about an alteration which had only skin-deep stress, but there was no doubt that the stress varied widely with the different materials of which the rails or the tires were composed. If those rails were, for instance, of cast iron, the effect of the rolling upon the actual strength of the rails—assuming them to be strong enough to resist the transverse stress due to mere weight and impact — would be to compress and gradually crumble the surface, and that crumbling would relieve the material below of the stress that otherwise, in different material, tougher and stronger, would grow, and in growing induce the small hair fractures, of which so much had been seen, not only in the sections shown by Mr. Kirkaldy, but also in some of the photomicrographs which had been thrown on the screen.[2] As to the intensity of the stress, if it was remembered, as Sir Frederick Bramwell had pointed out, that with a small amount of hammering on the inside of a piston-ring, the

[1] Minutes of Proceedings Inst. C.E., vol. xlvii. p. 43.
[2] British Association Report, 1896, p. 896.

Mr. Beaumont. compression brought about would induce a lengthening stress in that material sufficient, at the small radius that it had to act through, namely, the thickness of that ring, it was obvious that the stress must be very considerable. Before leaving Sir Frederick Bramwell's remarks, he would like to say that when he saw some difficulty with regard to the proof of this stress, and the other fact as to certain wrought-iron rails which were light and narrow, he thought perhaps Sir Frederick had overlooked two facts, namely, that in the cast-iron ring he referred to, the material was not free to flow under the hammering that was done more along the middle of the width of the ring than elsewhere, as it was along the narrow rail rolled all over the surface—a tough rail which would bend pretty freely, and which would be freed from the stresses that otherwise would accrue. As an example of that—he had not the Paper in his hands that he referred to, but as far as he remembered—of all the tires that broke with holes in them, about 80 per cent. broke through the solid rather than through the hollow. The lesson from that was that the stresses brought about by the growing compression in the material of the surface not free to flow in the body of the rail, was free to flow round about the edge of the hole, and flowing in that way was rubbed off and worn off and crumbled off in the use of the tire partly by rolling and partly by the use of the brakes. The reality of that stress was, he was glad to say, confirmed by these rail tests, and the lesson seemed to be that a material should be used not necessarily of the strongest and not necessarily of the hardest. With regard to safety, one of the most important points was, he thought, to have the rails of such large section, particularly in the head, that the strength of that head as compared with the stresses that would be set up in the part rolled and compressed as described, should be enormous. In that way he thought the life of the rails might be undoubtedly a very long one. There were several points in the Paper that made it necessary to refer to the capriciousness of rail fracture, and he would say that a reference to tire fracture was perhaps better calculated to give correct notions than a reference to the rail, because the tire on a locomotive wheel had a definite base upon which it ran. The rail, on the other hand, might have between supports a distance between a pair of chairs or a distance between two pairs of chairs, and the difficulty in arriving at a conclusion from some of the figures that Mr. Kirkaldy had given as to the fractures of different rails in different places arose no doubt from the conditions under which those rails worked in that respect. There was one more point. The question was obviously not entirely a metallurgical one, but one of mechanics and physics as well as metallurgy. The last point he would remark upon was that the unaffected strength of the rails on curves was further confirmation of the nature of the origin of those stresses. Mr. Beaumont.

Mr. J. R. BELL agreed with the conclusions Mr. Kirkaldy had expressed, less, however, with regard to the extra carbon than about the greater depth of rail. Apart from flaws he was surprised to find that a great difference was discovered between the deteriorated strength of the top and of the bottom flanges of the rails. Taking the action to be as suggested by the counter-flexure of the rail in passing over the points of support in the chairs, it seemed to him natural that the bottom would suffer in the converse way equally with the top; the bottom of the rail would be compressed over each chair seat just as the top was pulled out. He was pleased, however, to find that the tabulated figures for tension strains did not seem to point in all cases to such a great difference as a mere reading of the Paper would imply. He had not had the pleasure of hearing the whole of the discussion, but he felt strongly that Mr. Stirling's famous "Single-driver" engines had a good deal to do with the particular effect that was produced on the Great Northern rails. The tension exercised by a driving-wheel, especially at starting, was like trying to pull the skin of the rail over its head, and it seemed to him that that was calculated to account for a good deal of the development of the hair-cracks. However homogeneous the material of a rail, or tire, might be originally (and he was far from believing all bull-headed rails above reproach in this respect) Mr. Kirkaldy rightly stated that as the original rail-skin wore, a new one was perpetually reformed by "hammer-hardening." Possibly a photo-micrograph of the rail-skin might afford a revelation similar to that of Sir William's beautiful picture of tempered steel. Precisely the same effect by "cold rolling" must occur in tires, except that there the original skin was not worn off but removed in the lathe. Mr. Aspinall's photographs of driving-wheel tires corroborated Mr. Kirkaldy's view of the rail-skin. In either case a thin skin of stronger metal was welded to a softer body, and all the tractive force of the engine was engaged in pulling the skin of the rail back, while the weight of that wheel, like all the other rolling-loads, was trying to push the under metal forward, much as a pastrycook's roller pushed dough before it. When rails "crept," or tires ran slack, these considerations, coupled with the quality of the material, might help to explain the reason. Mr. Bell.

Mr. Bell. Whether, however, actual creep was disclosed or not, it seemed to him that these two tendencies were ever present and that their continued interaction made for the disintegration of the rail-head. The sum of these forces was in question where the rail was concerned and their difference in the harder worked tire. Either force appeared to vary directly with the weight on the tire and inversely with its diameter. Owing to greater discrepancy between the skin and the body, it was probable that a deep bull-head was more liable to disintegrate than that of a more symmetrical rail. He could not recall any serious failure of a steel rail in India, except where appreciable creep had occurred with a deep-headed rail section. It was not uncommon for a heavy express engine to deliver a tractive effort of about 6 tons on the draw-bar, or 3 tons reaction on each rail, and this stress upon a very thin skin was obviously better applied to two points of the rail and coincidentally to two tires than to one. In axles, which also acquired cold-rolled skins, a long journal was subject to counterflexures as well as plastic, "creep-like" flow, and it might be suggested that shorter American proportions of journals might avoid the troubles with hair-cracked steel journals that were far from uncommon with long journals. Whether or no Mr. Kirkaldy's fruitful suggestion, that the starting-points were the weakest spots in rails, led towards a return to double-headed rails and to inverting them at short intervals seemed almost a moot point. It might be that in this matter the present generation were not much wiser than their fathers, and it was certainly cheaper to invert rails than to anneal them.

Mr. R. Johnson. Mr. RICHARD JOHNSON desired to bear his testimony to the good work done by David Kirkaldy, and he was glad his mantle had fallen upon his son, whom he congratulated upon the Paper he had put before the Institution. He should like, if he could see his way, to speak to the practical use of the Paper. Engineers had been for a good many years past working on steel rails; his Company commenced by paying £18 a ton for steel rails, and pretty nearly ended by paying £3 12*s.* 6*d.* He was very much of the opinion of Mr. T. R. Johnson, that there was not work enough put into the ingot before rolling. When his friend Mr. Price-Williams was at Deepcar he had a steam-hammer connected with his rail plant, but he thought it would puzzle Mr. Price-Williams now to find a steam-hammer in a rail plant at all. He was strongly of opinion that if a rail was wanted to wear, work must be put into it. It should not be lost sight of that probably the weights on driving-wheels to-day were nearly double what they were in the year 1862 when steel rails were commenced to be used. Those engines must be punishing the rails very severely, and it struck him that that was the direction which must be looked to in connection with the manufacture of the rail. He thought work must be put into it. Mr. Kirkaldy had very properly suggested that engineers should look out for such fractures. He had to send several pieces of rail to a gentleman in the North of England, who sent him the result, with the suggestion that in future the leading platelayers should be supplied with emery paper that they might polish the surface of the rail to look for those fractures. That was not practicable, and he took very little notice of the suggestion. If rails lived as rails had lived for something like 20 years, probably, at the present price of rails, that was as much as could be expected; but he would strongly recommend that perhaps 5*s*., 10*s*., or even 15*s*. a ton should be spent on putting more work into the ingots. Mr. R. Johnson.

Mr. PRICE-WILLIAMS observed that a steam-hammer was never used at Stockbridge, in hammering the ingots for rails or any other purpose, and he thought it was only due to Mr. Fox to say that he would not allow it, and rail contracts were declined because they were required to be hammered. Mr. Price-Williams.

Mr. RICHARD JOHNSON could only add that the best rails he had ever used were made from hammered ingots. Mr. R. Johnson.

Mr. F. W. HARBOARD considered that the bending test suggested by the Author must throw very great light on the effect of wear upon rails, but he did not think that Mr. Kirkaldy's conclusion, that the head of hard rails—by which he assumed he meant rails which necessarily contained more carbon—were less likely to develop cracks, was supported by theoretical considerations, or borne out by practice. Referring to his own Paper Mr. Kirkaldy gave the tensile tests of three rails (page 142), in which Nos. 1 and 3 gave respectively 51·5 tons and 47·6 tons per square inch, and No. 2 6 tons. All those rails were what would be considered hard rails, in fact anything above 43 tons was a hard rail. A 40-ton rail was about what he considered the maximum tensile for good rail steel. Of these three rails mentioned by Mr. Kirkaldy, two at least showed the surface-flaws, which he said were not so likely to develop in hard rails, and only one, which certainly was the hardest of the three, did not. Then Mr. Kirkaldy supported his contention by referring later on to very soft rails which showed flaws and which he said gave a tensile test of only about Mr. Harboard.

Mr. Harboard. 33 tons. That was practically mild steel, and a great deal of bridge-steel gave from 28 tons to 32 tons, and nobody would suggest that rails should be made as soft as bridge-steel. He had been trying some bending tests with the assistance of Professor Hearson, who had kindly made them for him. The test was suggested by Mr. Stead some time ago. At Coopers Hill there were not the facilities for bending rails in the same way that Mr. Kirkaldy had done, and he had been in the habit of cutting a piece off the head from $\frac{3}{8}$ inch to $\frac{1}{2}$ inch or more, as the case might be, taking care for comparison that they were all the same thickness, and bending them in compression and extension, and he had tested six rails in this way and the results varied very much. In one case a rail which was very soft, containing about 0·34 carbon, after 19 years' wear, bent over practically to the same extent both in extension and compression and showed no surface cracks. In the case of a hard rail containing 0·6 of carbon, which had only been down two years, the head in extension gave evidence of considerable hardening, as shown by its bending considerably more when tested with running surface in compression. There was one other point in Mr. Kirkaldy's Paper he wished to refer to, and that was whether some of the surface cracks might not possibly be due to sulphur in the rail. It was well known that with a certain amount of sulphur in a rail, during the rolling little incipient cracks were formed which would not be visible, but which might develop with cold work. With regard to the question of the analysis it was very important that railway engineers should realize there were two classes of constituents in steel, those which were essentials like carbon and manganese, which the manufacturer had to vary according to the mechanical tests the steel was required to stand, and those which like sulphur and phosphorus might be regarded as impurities pure and simple. It was distinctly advisable to consult with the manufacturer as to the proportion of carbon and manganese necessary, and these should then be specified within such limits that the mechanical tests could be readily obtained in ordinary work, but with regard to sulphur and phosphorus these were not required and need never be high, provided pure materials were used and care taken in the manufacture. High phosphorus or sulphur either meant impure materials or bad workmanship, and the engineer might reasonably ask to be protected against these by specifying that they should not exceed certain limits for different classes of steel. He thought it was in the interest both of steel makers and engineers that the latter should specify that the impurities other than carbon and manganese should not exceed certain limits and so ensure a high-class material being obtained. Mr. Harboard.

Sir WILLIAM ROBERTS-AUSTEN, in reply, said that, generally speaking, a micro-section cut from the head of a rail did represent very fairly the general structure of that rail, but the extent to which differences occurred he attempted to show by the section of the rail provided by Mr. Kirkaldy, of which he exhibited several sections. It might be perhaps remembered that the portion taken from the web differed from the rest in having its structure elongated; but speaking generally, one section represented the whole rail very fairly. He had very often attempted to get sections at right angles. A rail, as he said, resembled a rock, that was, the pearlite and the carbide, being as it were, the mica of the granite. If a longitudinal section was taken there was some different geometrical relation between the pearlite and the ferrite that would be found in the mica and quartz of a distorted granite, but not to any very great extent. That structure obviously went through the entire rail, exactly as the same structure was found, speaking generally, in a mass of granite. He had found many cases in which the fracture crossed indifferently both the ferrite and pearlite area. On the other hand, he had found some cases in which, as Mr. Andrews very justly said, the fracture followed the lines of the pearlite. With reference to Professor Arnold's remarks, he would point out that the title of his Paper was the photo-micrography of steel rails, and in stating that this question had not been previously brought before the Institute, he did not contemplate drawings of micro-sections, in which form the question of steel rails had been previously brought before the Institution. In answer to Mr. Andrews, he was in some little difficulty, because although Mr. Andrews' contribution to the discussion mainly dealt with photo-micrography, he did not discuss his Paper. Therefore he was in some little difficulty in knowing how far they differed, or whether they differed at all. So far as he knew they only differed in one point, namely, that he vastly preferred photographs and Mr. Andrews preferred drawings. The members had seen the photographs that Mr. Frewen Jenkin had thrown on the screen, and it was not for him to say which were preferable, drawings or photographs. He merely said that he infinitely preferred photographs. Photographs could easily be obtained which would reveal all that a drawing could be made to show. With regard to Mr. Frewin Jenkin's most interesting communication, he should just mention that Osmond's method was not the only method he employed, but he had purposely limited Sir William Roberts-Austen.

Sir William Roberts-Austen. the range of his communication by saying in the Paper "that the consideration of the subject had in the present notes been restricted to the narrowest possible limits." References to slag flaws or to sulphur flaws had been omitted, as it was desirable to direct discussion of the subject mainly to the question of the relative areas of pearlite and ferrite. Had he wished to show the sulphur flaws or the slag flaws, he could have done so with the greatest ease, he should have etched the specimens differently. He agreed with Mr. Frewen Jenkin in thinking that Osmond's method was infinitely preferable to the other methods which had been mentioned. Mr. Inglis had asked him whether "hammer hardening" might alter the rate of expansion in different parts of the rails. He considered that such would probably be the case, and that the subject well deserved attention. Mr. Inglis had also referred to the question of fineness of grain, and Sir William would point out that some time ago Mr. Osmond and he had shown [1] that in certain crystalline alloys annealing at what seemed to be an inadequately low temperature produced fineness of grain. It might, therefore, be well, with this object in view, to heat a rail (before its rolling was finished, or after) to a temperature below that at which the carbon of the pearlite would diffuse into the ferrite.

Mr. Preece. Mr. W. H. PREECE, C.B., President, thought some of the members would like to have Sir William Roberts-Austen's opinion on a certain point. From the photographs and drawings it would appear that steel rails were rather a mechanical mixture, as he could see Sir William believed, because he referred to granite as being a kind of analogous substance. Did Sir William think there was a line of cleavage through the rail similar to lines of cleavage met with in rocks like granite?

Mr. Harris. Mr. GRAHAM HARRIS desired to supplement that, and to ask was the line of cleavage, if it did exist, affected by the "work," and the manner in which the work was put upon the rail?

Sir William Roberts-Austen. Sir WILLIAM ROBERTS-AUSTEN said the whole object of his communication was to draw attention to the fact that a steel rail was not a uniform material—that it was in fact a solidified solution of carburized iron from which certain constituents, mainly the pearlite, that was the carbide, had separated out as the mass cooled down. Had the rail been quenched, there would have been a more or less glassy uniform material, which

[1] Philosophical Transactions of the Royal Society, vol. 187 (1896), pp. 417–432.

might possibly show cleavage. In his belief, though it did not rest on accurate experimental evidence, there were no true cleavage planes analogous to those found in slags or other rocks. Sir William Roberts-Austen.

Mr. W. G. KIRKALDY, in replying, said it was unnecessary to say how very gratified he had been by the reception of his Paper, and he mentioned especially the personal gratification he felt from the very kind remarks with which the President introduced the proposal for thanks, coupling it with his father's name. He felt it a great honour and a great responsibility to follow in his footsteps, but he was doing his best to keep up the traditions that he had set for him. A sketch of how the Paper started might be interesting. He had written it in quite a tentative manner. He had not attempted to deal conclusively with the subject; it was much too complex. But he did his best, first of all, to show the tests that he had been able to make, which he thought would simplify the matter somewhat; that was, to provide fairly simple mechanical tests by which an engineer could judge of the deterioration which had taken place. That was the point from which he had started, and he thought the method of the duplicate bending test afforded a means of judging what deterioration was set up in a very practical and simple way, and one which could be followed out at any works. He also wished to point out that the difficulty with tensile tests was that the experimenter often did not hit on the deterioration which might exist in the rail head. He fancied that might have been overlooked in previous years in making mechanical tests. Often in a rail which might be in a defective condition very good physical results were obtained. But that was owing to the nature of the tests; in a tensile specimen the top surface of the rail could not be included. He thought that was overcome by the bending test in the inverted form. If there was any deterioration it was discovered. Testing it in the normal way gave a fairly ready practical method of judging what the rail was originally. The records could not be referred to to show the original condition of the rail, but he thought the bending test gave that sufficiently close. With regard to Sir Lowthian Bell's glass experiments, he thought they rather proved his case. Glass afforded a sufficiently near illustration for steel. When Sir Lowthian Bell had the glass loaded in the centre and a very slight scratch underneath it showed what a remarkable falling off there was in strength, it did not seem to occur to Sir Lowthian Bell that a similar thing took place in a rail through looking at it from the point of view that the head would be always in compression. The trouble was that the head was not Mr. Kirkaldy.

Mr. Kirkaldy. always in that condition. It was constantly varying; as the load shifted along, the point in compression a moment before became in tension owing to the deflection of the rail as the wheels travelled along. Therefore the glass illustrated rather well how, if any mechanical flaw started in the rail head, it was of serious moment. He would have been very pleased to have seen some photo-micrographs of some of the flaws he had shown in the rail head. He had called them hair cracks. If it could be found by means of the microscope whether the cracks followed any line of cleavage it would be of great assistance. It occurred to him that if it went straight across regardless of the structure, it would point rather to being a mechanical trouble. If the microscope proved it followed the interlocking lines, then if the metallurgist could give a structure of steel more interlocked, he thought it would last better under practical conditions. It was not at all surprising that Sir Lowthian Bell should have found the question of breakage of rails such a very complex and contradictory one, because by ignoring mechanically induced flaws as of no consequence, and therefore endeavouring to explain breakages merely from the chemical standpoint, many inexplicable cases would naturally be found. This illustrated the advisability of examining cases of breakdown from a mechanical as well as from a chemical standpoint. He sympathized with Sir Lowthian Bell's remarks as to the low prices obtained for steel rails; this was a point which he had discussed with several engineers, namely the advisability of paying a somewhat higher price per ton in order to secure a better quality; for instance, to provide for more being cut away from the crop at top end of each ingot, because so many failures at the ends of rails were undoubtedly due to insufficient metal being cut away. He had deemed it better to let information regarding chemical composition be added subsequently, by those who had special experience in that department. The results of chemical analyses had been incorporated, however, in several instances on the manuscript reports which accompanied the Paper, and which might be consulted in the Library. The few Tables printed as Appendixes were merely to illustrate the method of reporting results on the tests, and especially the marked difference between the inverted and normal direction of bending tests, but these Tables gave only a meagre idea of the extent of the experiments. The manuscript reports contained over 230 separate experiments, which again were selected as the more interesting among a still larger quantity. It might be of interest to give the analysis of the piece of rail from which Sir William Roberts-Austen had prepared the fine series of photo-micrographs shown in Plate 3. Carbon 0·520, silicon 0·043, sulphur 0·109, phosphorus 0·049, arsenic 0·035, manganese 0·360, copper trace, iron 98·884. The tensile strength of the bottom of the rail was 45·6 tons, contraction of area at fracture 29·1 per cent., extension in 10 inches 14·7 per cent. Mr. Snelus's question whether the cracks were developed in flange-rails to the same extent as in bull-headed and double-headed rails raised a very interesting point, but one which, up to the present, he had had no opportunity of investigating, so could not express any opinion. He would mention in passing, however, that if flange-rails were used the edges of the flanges ought not to be notched for the spikes. When investigating the cause of breakage of a number of flange rails, he found that in every case failure had occurred, not from the top or head as those shown in the Paper, but from a flaw induced in the flange at the angle of the spike-notch (which in those instances were all cut out square, with sharp corners). If notches must be employed with that class of rail to prevent "creeping," such ought at least to be rounded out so as not to leave any sharp corner. This was mentioned merely to show how very sensitive steel was to any detrimental form. The remarks of Mr. Inglis as to American engineers having adopted standard sections for rails was an interesting indorsement of the views advocated by the late Mr. David Kirkaldy. There was, however, another very important part of Mr. Kirkaldy's scheme, namely not only to fix upon definite standard sections, for a regular series of weights or sizes, but further that a standard quality of steel as to mechanical tests, &c., should be agreed upon in order that rail makers could, in time of slackness, roll rails for stock to keep their mills going, and under such conditions in all probability produce more uniform and better grade rails than when heavy orders had to be pushed through at a great speed, hardly giving time for proper inspection and entailing much more extensive plant, &c. His idea being that makers should be enabled to work under as uniform and as regular conditions as could be devised. There was much to be said in favour of these views even at the present time, and he trusted that standard sections and specifications would be attained. Mr. Inglis's remarks as to increasing the width of the head of a rail were well worthy of consideration, especially if the increase in width were made use of to increase the bearing for the tire, which would economise the turning up of same and also render the effects of the traffic less severe upon the rail. He did not object Mr. Kirkaldy.

Mr. Kirkaldy. to the drop test in its proper place and used for its legitimate purpose, namely, the testing of new rails to determine rapidly whether they be suitable, and to weed out defective rails, where the engineer was more anxious to avoid brittle or defective rails than to know exactly the quality. He agreed that from this standpoint the drop test was useful, yet its tendency was always towards the favouring of a softer steel. But when commencing his investigation as to the effects of wear upon rails he considered that to attempt to ascertain data as to the extent of the deterioration set up in rails by means of the drop test would be practically wasting time, and he therefore inserted his views in the Paper. He was open to conviction, however, and would be glad to have the privilege of witnessing any tests in this direction upon worn rails, where any engineer found that he could determine the degree of deterioration. The static or pressure tests in the examples brought forward were sufficient not only to show the presence, but to gauge the relative extent of deterioration very closely. In the cases of some worn rails tested by the Author, of which portions were also tested under the tup or falling weight, he found that the rails which withstood his inverted bending test satisfactorily also withstood the falling-weight test; while in the case of a rail which was reported unsatisfactory under the falling-weight test a similar result was shown by the Author's pressure test. It would be highly interesting to be able to carry out comparative tests in this direction on a more extended scale. Mr. Inglis mentioned that a 95-lb. or 100-lb. rail provided a sufficiently strong girder for all requirements; this was readily granted, but the whole tenour of the Author's views had been rather to endeavour to improve the grade of steel and keep down the weight, as it appeared open to question whether longer service would be obtained from the heavier sections. If weights were increased and relaying was carried out upon a wide scale the question was merely postponed for many years, but it was a very costly matter in the meantime. Moreover, had it been proved as yet that the present rails were too weak, or that the bulk of them were to any extent in an unfit condition? In reference to the instance which Mr. Inglis mentioned of his increasing the number of sleepers per rail under certain conditions, he thought the better the condition in which the road could be kept the better for the rail. If full information could be obtained in cases of rails failing he believed that it would be found in many instances that the road had been in poor condition, entailing abnormal deflection in the rail, and so accen-

Mr. Kirkaldy. tuating the effects of the traffic. His suggestion of deepening the rail would tend to ameliorate such conditions, but with the increase in rolling loads it was possible that a larger sleeper area as well would prove economical in maintenance. He was much indebted to Mr. Ross for furnishing the results of analyses of several of the rails dealt with. Regarding the Table computed from ten different analyses of the same rail showing the extremes and mean results, he thought that the wide divergence shown in some of the constituents might be due to difference in making the analyses, and not entirely to difference in the steel. The analyses (Table II, p. 170) of the hardest and the softest of the six rails, taken from the line near Misterton, were of special interest, as $50\frac{1}{2}$ million tons had passed over those rails, and yet there was no appreciable deterioration set up. The tensile strength of the hardest was 45·4 tons, contraction of area 36·4 per cent., and extension in 10 inches 18·8 per cent. In the Author's opinion the chemical composition as to carbon and manganese was noteworthy. With reference to Table III, giving analysis of what was termed an "ideal" rail, he felt some doubt as to the phosphorus being really as high as the proportion given, as such was scarcely compatible with the physical qualities. The cuttings for this analysis had not been supplied by the Author, so there might be a possibility of the analysis representing another rail. He might emphasize perhaps one part of his Paper which had not been fully kept in view. He thought it was very important to know the conditions under which each rail was used. He could classify it almost in this way: if the conditions were favourable, a straight line and no stoppages, he believed practically any grade of steel within moderate range would give satisfactory results. There was one which he showed, which he termed an ideal rail, and he thought he must still adhere to that in the sense in which he meant it. It had had 23 years' main-line traffic on the Great Northern Railway, and under the bending test it practically showed no deterioration whatever. Chemically, it might be that it was not an ideal rail. He thought in considering the question it should be brought down to a narrow compass by looking for the steel which would stand best under unfavourable conditions. He thought the steel made at present sufficiently answered all purposes where the conditions were favourable. He thought there need be no alarm felt about it. The chances were that the flaws were only induced under severe conditions, and the point which might be followed up with most benefit by railway engineers who cared to go into it would be the effect of the starting-action or the

Mr. Kirkaldy. skidding-action. He thought a great deal in the behaviour of rails depended on the mechanical conditions under which they had been made. Possibly more lay in that even than in the range of the chemical constituents—whether the right amount of work had been put into the rail and at the right heat. He thought it should be investigated; what differences arose, say, from casting the ingot, then letting it soak in the pit, and cogging it and rolling it right away. Did that give a different steel from one which in the older days would be allowed to cool off, then be re-heated, possibly hammered, or just cogged and rolled? He was rather afraid of obtaining hardness by high carbon, and he thought it would not be wise; his feeling had been for a rather moderate carbon. To obtain hardness by manganese seemed the readiest way. Mr. F. E. Robertson criticized the use of the term "stress" in the bending tests; this term had always been perfectly well understood by engineers to whom reports upon experiments had been sent in all parts of he world during so many years. There did not appear to the Author to be any valid ground for misconstruing the terms employed; had the words "stress in pounds" referred to stress produced in the bottom of the rail by the imposition of another load it would have been properly described as such, and both amounts duly stated. Mr. Robertson seemed to have overlooked the extensive manuscript Appendixes contributed with the Paper, which might be consulted in the Library. It was the custom of the Author's firm to arrange test results in the order of merit wherever practicable, but the originals of these few reports were not thus arranged, being exceptional, and it was not considered necessary to rearrange them for the purpose of the Paper, as they were printed in the Appendix merely to show contents of reports. As regarded the views he expressed, that "it seemed *à priori* not unreasonable to suppose that a harder steel would resist better the local action of the wheels than a softer steel, and so escape the incipient flaws which ultimately led to fracture," he agreed that a harder and tough steel would stand better. If the conditions of the modern wheel-loads and the small base or area of contact upon which the tire bears were realized, the actual compressive stress upon the steel was very high. It was very difficult, almost impracticable, to define the extent of bearing area, as the conditions varied greatly between various-sized wheels, tires in different condition as to form, and whether the rail had a slightly- or much-rounded top. Certainly the pressure imposed on the rail-head was very severe. Now if the rail be of soft steel the metal could not withstand this pressure, but yielded and flowed, in many cases working out over the edges of the top in a thin scab or fold, and it was during that severe process of cold rolling and beating out of the top that there appeared to be the real risk of induction of the hair-cracks which he had shown. On the other hand, if a harder, but at the same time tough, steel be employed it would not be disturbed so much under the pressure imposed, and therefore it was quite reasonable to expect that less change should be produced in the metal. It must be carefully borne in mind that in advocating a somewhat harder steel than usually employed he did not intend mere hardness, but rather a stronger and tougher steel. It should also be borne in mind that it did not necessarily follow that because in the past rails of moderate hardness had worn well in practice that new rails of similar grade would do the same in the future. In the past, at the time when some of the aged rails were laid, the wheel-loads were much less than now; in course of time the heads of those rails became gradually planished or hammer-hardened, practically representing a harder steel. This hardened top once formed, when free from induced flaws, had sufficed wonderfully well for resisting the action of the heavier modern wheel-loads; but he thought that if in new rails it was attempted to reproduce (because it was open to question whether the modern rolling of rails produced an equally good mechanical or physical condition of the steel) the steel of say 20 years ago, it might be found that the intensity of the traffic would punish such medium grade steel very rapidly, and once induced flaws were set up the life of a rail became most uncertain and erratic, and notwithstanding that the section might be made much heavier the final life might prove very disappointing. It was with these ideas that the Author thought it prudent to aim for a harder yet tough steel, and that special care be taken in all the stages of rolling to toughen the steel mechanically as far as practicable. He might adopt Mr. Robertson's simile or illustration of the matter of wire-drawing only he felt it scarcely applicable. In drawing wire the harder grade doubtless had to be annealed more frequently for practical considerations to render it workable and permit of its being drawn down smaller until the required size be reached, the final produce being a very fine material. Now, if it were practicable to finish rails by a similar cold-drawing process he believed that it would place the steel in a much better condition for resisting the induction of flaws, as well as obtaining greater wear-resisting capacities. In other words, if such process could be done during manufacture the rail would be better, being in such case more Mr. Kirkaldy.

Mr. Kirkaldy. homogeneous throughout than was the case at present, where a softer rail had its top surface only beaten into a hard dense skin which was merely dead hard but deficient in toughness, and was therefore not in a favourable condition to accommodate itself to the movement or spring in the rail during the passing of trains. He was obliged to Mr. Robertson for bringing forward the interesting information regarding American practice in the matter of specifications for chemical composition of rails. It appeared as if the high carbon specified for the heaviest sections was a short-cut, so to speak, to obtain wear-resisting steel without putting so much work upon it during rolling. It would be very interesting to know the dimensions of the ingots used for producing the 100-lb. rails. It should be preferable or safer to make sure that with heavier rails they received the same or even a greater proportion of work in rolling by insisting upon having the cross dimensions of the ingots sufficiently large. This was only mentioned as a suggestion, as it appeared on the face of the specified analysis as if hardness were being obtained in America in the direction of mere "chemical hardness," which was not what appealed to the Author when forming his conclusion that the direction for improvement tended toward a harder steel. He was gratified by the kindly manner in which Professor Arnold had offered to carry out micrographical examinations upon samples of worn steel rail, and he hoped to avail himself of such kind co-operation in the cases of special interest. He trusted that in the future there might be opportunities for carrying further this investigation upon rails carefully selected from defined positions and of ascertained duty, in one direction giving the preference in selection to rails which had behaved the best under long service, and in the other direction selecting the rails which had behaved unsatisfactorily, with a view of determining what to avoid and, on the other hand, what to aim at in making new rails.

Mr. Preece. Mr. W. H. Preece, C.B., President, thought the members had every reason to congratulate themselves upon an admirable, well-sustained, instructive, and interesting discussion on a most important subject. The Institution was deeply indebted to the two Authors for bringing before it Papers on such different lines. They showed what the members wanted to see a little more of, namely, the intimate connection which existed between the engineering profession and the scientific world. He had said before that the engineering profession was based directly on the facts of science, and the more the Institution could obtain scientific spirits like Sir William Roberts-Austen to come before it and give the scientific aspects of the questions, and other practical men like Mr. Kirkaldy dealing with such questions from the practical point of view, the more the world would see there was no separation between engineering and science. Mr. Preece.

Correspondence.

Mr. Barker. Mr. JOHN BARKER considered that Mr. Kirkaldy had shown great sagacity and skill in the experiments he had made and recorded, but he thought some of the deductions therefrom were not justified. The subject was wide and required treating on a broad scale, beginning with the raw pig-iron through every stage of manufacture to the worn or fractured rail. The large proportion of fractures found at or near the ends of rails was doubtless chiefly due to the fact that too little "crop end" had been cut off. Another cause was the fact that the earlier steel rails had the fish-bolt holes punched in them and were not rymered out. He apprehended that it was now well known that even rails of good quality were most seriously injured by punching holes in them, rendering them incapable of resisting the impact of blows. If the steel were of inferior quality the detrimental effect of punching was accentuated. The amount of "crop end" cut off varied considerably. He had found that the number of defective rails diminished in proportion as the length of crop cut off was increased. It had been his duty to witness a large number of ingots sawn through in order to ascertain to what extent they were unsound. The experience so acquired had convinced him that as a rule too little crop was cut off. The "pipe," or hollow and honeycombed portion of ingots, extended from the top to one-third or one-fourth of the length. In the case of rails all the "pipe" was rolled into the rail bar, excepting that in some cases a small piece was sheared off the bloom after the ingot had been cogged down in the roughing rolls. In other words, the impurities and honeycombed portion of the top of the ingot were "rolled in," and very little was "cut off" after the rail bar was rolled. As the rail bars varied in length between 100 feet and 200 feet, to merely cut off from 2 feet to 6 feet was insufficient to get rid of the unsound portion. The pent-up gas and impurities were largely rolled into that rail which was made from nearest the top end of the ingot. He was convinced that in many cases the cracks referred