Mr. Sellon. very similar to those put forward in his Paper, which might be summed up as saying that corrugation was a form of surface failure of the metal, and that to prevent it the one method was to increase the resistance of the metal to the stresses it had to endure. Mr. Busse concluded his report with the following sentence:—

> "We observe, before concluding, that the experiments, the experimental analyses and the metallurgical researches of the Commission appointed by the German Union of Tramways and Light Railways for the study of rail corrugations have not yet resulted in determining the factors of the phenomenon."

Mr. Sellon had, however, endeavoured to carry the matter a little farther, by exhibiting the nature of the failure, and suggesting the direction in which the qualities of the steel needed to be improved. In this connection Mr. Shortt's statements that the micro-structure of Sandberg steel showed homogeneous pearlite, with no ferrite network, and that the same kind of structure was shown by Bessemer acid rail having 0·8 per cent. of carbon, appeared to him to be highly significant.

Correspondence.

Mr. Aigeltinger. Mr. A. Aigeltinger, of New York, observed that it might be of interest to give a brief account of the uses to which rolled manganese-steel rails had been applied in the United States. The rails were, of course, first employed for points and crossings. English engineers had been familiar for many years with this application of rolled manganese-steel, and he would merely say that the manufacture of such special work had developed very rapidly, so that now almost any design which could be furnished in ordinary rails might be duplicated in rolled manganese-steel, and there was now at least 1,000 tons of this material in use. The second use to which the rails were applied was on curves on the electric railways. The first installation was on a single curve on one of the New York subways, and after a short test 300 tons were put in the worst curves for trial. At the end of 3 years it was found that the average life of these rails was a little more than 5½ times that of the 0·8 per cent. carbon open-hearth steel rails. This was but one test of several, and now rolled manganese-steel rails had been made the standard in New York for curves with radii of 900 feet or less. There were more than 2,000 tons of this rail in service on the electric lines of New York, Chicago, and Philadelphia. The third, and principal, use was on curves and other places of severe wear on steam railways. The results shown there were equally as good as those obtained on the electric lines. For this use the rail had outgrown the experimental stage, and several of the large American railways had laid down more than 500 tons each. The wear in terminal stations was exceptionally severe in some cases, and here several railways had adopted manganese-steel rails, the largest installation perhaps being that in the new Grand Central Station at New York of the New York Central and Hudson River Railroad, where about 500 tons of a special 105-lb. section would be laid. The fourth use was in tunnels, where the effects of corrosion were noticed most quickly. The results obtained by an accelerated acid test, as stated in Mr. Willox's Paper, had been confirmed by actual experience in tunnels where the rails had been in service for more than a year, and where the results were so encouraging as to cause the railway making the test to lay similar rails in other tunnels. Mr. Aigeltinger.

Mr. E. HEATHCOTE BEAL considered that corrugations on rails, and especially tramway-rails, were probably produced by the wheels bearing not on the whole width of the tread, but merely on a small portion of the tread, producing a tendency for the rail to curve in a horizontal plane if either the inside or the outside portion of the tread was being subjected to the rolling action of the wheels. If the centre portion of the tread were subjected to the rolling action, the ends of the rail would tend to curve downwards, as the rolled surface had been elongated by the greater load per square inch due to insufficient contact of the wheels; but this tendency to bend was prevented by the rails being wedged rigidly down to yokes, hence the elongated surface puckered up. This puckering appeared to him to be corrugation, and accounted for the irregular shape of the corrugations, the shape depending upon the portion of the tread in contact with the wheels; while it would also account for corrugations appearing on the wheels themselves, as the same action was taking place. Mr. Beal.

Mr. PERCY S. J. COOPER, of Middlesbrough, observed, with reference to Mr. Sellon's statements that rails containing a high percentage of carbon were practically free from corrugation, and that a high percentage of silicon was very beneficial, that he agreed with this latter statement; but did not the Author advocate a lower carbon content than 0·6 when adding silicon also? The North Eastern Steel Company had made many thousand tons of silicon tramway-rails, showing on analysis approximately 0·28 per cent. silicon and 0·47 per cent. carbon, which were believed to have Mr. Cooper.

Mr. Cooper. given satisfactory results. While many causes tending to produce corrugation had been dealt with, could not something be done to minimize the vibration which took place between the car and the rail, which undoubtedly was one of the chief causes of corrugation? Mr. Cooper considered that the manufacturer of railway material was saddled with much more than his share of the blame. He agreed with Mr. Sellon's remarks on drop testing for tramway-rails, and would suggest that, should higher-carbon rails be demanded, the tup test should be modified proportionately, as a Brinell test represented the stress to which a rail was subjected in the track.

Mr. Fergusson. Mr. JOHN C. FERGUSSON stated that his experience in electric traction commenced with the building of the Seattle tramways in 1889. He admitted that there were changes and forces in electric traction peculiar to that class of work. The form of a tramway-rail, with its groove and guard, was in itself a cause of wear, particularly since the Board of Trade had reduced the size of the grooves and the guards of the rails to the smallest possible dimensions, to please the road-authorities, until there was no margin of safety left with regard to the wheels keeping on the rails. These compulsory conditions necessitated exact adjustment of the gauge of the flanges of the wheels to the grooves of the rail, otherwise wear and tear would begin at once. Undue wear in the rails and the rolling stock was due primarily to lack of skill in laying the track and in keeping the car-wheels true to gauge, although there were some causes inherent in the system, which had not been treated successfully. Good platelaying was difficult when the rails had to be laid so as to follow the curbs and the short curves of very narrow streets. This reason, however, could not be set up as an excuse for all the inexact curves, the misfit points, want of proper leads to crossings and to facing points on running-lines opposite car-sheds and workshops, and great ruts in the points and crossings. These real and evident causes of destruction to the rails were due to simple inexperience. A large saving in maintenance might be effected by gauging the wheels of the trucks daily; for in a city where a large number of cars were in use, some of them were certain to be out of gauge sometimes, and these were very destructive to the rails. Anyone who had examined old car-wheels was puzzled to know how they could have remained on the lines so long, for the flanges had been worn away. Very little would be gained by the small increase in the size of the wheels that might be practicable; for the increase of the surface contact between the wheels and the rails would be very slight, and both cast-iron and steel wheels were absolutely rigid and unyielding under the loads they had to carry. There was no doubt severe wearing action on the rails when a car was started, because the wheels were small and the motor was fixed. The corrugation frequently found at a point of curvature, on the outer rail, was due to the knock or bump against the outer rail, which might be felt, as a car entered a curve and was deflected from the straight. The check given to the car, and the consequent grinding of the wheels on the rails at this point, when more power was applied at the motor as it strove to recover, was sure to have a severe effect on the rail. The corrugation of the streets by motor-omnibuses commenced with a hole in the roadway; the omnibus gave a jump and the wheels descended heavily on the road and made another hole; one rut was the cause of others. With regard to the working action of electric-car wheels on the rails, he would suggest that where all the wheels of a tramcar-truck were used as driving-wheels, and particularly where the flanges of the wheels ran in grooves, the wheels did not work in the same plane, and thus their flanges obtained a horizontal grip across the grooves in the rails, which prevented the wheels from slipping and gave them extra adhesion to the rails. This action was noticeable when a car turned a curve, and it accounted partially for the wonderful climbing power up steep gradients possessed by an electric car, as compared with a locomotive engine. In support of this theory he might mention that at Seattle, Washington, U.S.A., in 1889, he used to watch a loaded electric tramcar ascend a gradient of 11 per cent. and turn round a curve of 1 chain radius on to Second Street. As one half of the curve was on the incline, the power required was enormous. In fact, the achievement seemed so remarkable at the time that some tramway journals expressed a belief that some magnetic attraction must exist between the wheels and the rails. To him, who had frequently watched a great Fell engine panting up to the summit of the Rimutaka mountain in New Zealand, holding on to a central rail, the easy performance of the electric truck was surprising. Allowing that great extra power was required by the car to turn through the 1-chain curve, the task performed appeared quite equal to the ascent of a gradient of 16 per cent., at about which incline the "adhesion" of steel on steel ceased; so that to accomplish this ascent something more was required than the mere adhesion of the tires to the rail-table. Of course the result was due mainly to the independent action of each wheel, used as a driving-wheel, and each working at a separate point on the rails; but the grip of the flanges in the grooves increased the Mr. Fergusson.

Mr. Fergusson. holding power of the wheels on the rails. With regard to the question of "rail-steels," in the case of tramway-rails supported from below through their entire length by a flat bed of concrete, he would suggest raising the carbon in the rail-steel to 0·7 or even 0·8 per cent. He would not raise the carbon to 0·7 in rails that were to be laid on sleepers. The silicon might remain at about 0·2 per cent., as it reduced elongation, which tended to brittleness. A good, hard, durable tramway-rail would be one containing carbon 0·7 to 0·8 per cent.; silicon 0·25 per cent.; sulphur 0·02 per cent., and phosphorus 0·03 per cent. This would give a tensile strength of about 65 to 70 tons per square inch, with an elongation of, say, about 11 per cent. This rail would cost less than a high-silicon rail, and only a fraction of the cost of a manganese-steel rail.

Mr. Harbord. Mr. F. W. HARBORD observed that Mr. Willox's Paper was of special interest, as although silicon rails had been in use in England and in other countries for some years, and titanium rails had been tried on a fairly large scale in America, the results now given were, so far as he was aware, the first published records of systematic comparative trials of these rails with ordinary carbon-steel rails in actual service. Silicon had been known for many years to increase considerably the soundness of steel ingots, and the mechanical tests gave better results in many respects than those obtained with ordinary carbon steel; but no mechanical tests could determine the life of a rail in the road-bed, and it was only by the accumulation of such detailed data as those given by Mr. Willox that the advantages and disadvantages of any particular steel could be determined. The addition of silicon to molten steel had the effect of removing blow-holes and of increasing the solidity of the steel, but at the same time, like all deoxidizing agents, it increased the depth of the central cavity, or "pipe," which was present in all steel ingots. The reason was that as the numerous cavities and blow-holes distributed over the entire section of ordinary carbon steel were closed by the addition of silicon, the resulting contraction of the metal increased the size of the centre cavity. That was one reason why silicon steel must always be rather more expensive to make than ordinary carbon steel, as a larger portion of the top end of the ingot, after it was rolled into bloom or rail, had to be discarded or scrapped to make sure of removing this pipe. The difference of depth of the pipe in silicon and ordinary steel was not very great, and if this pipe were removed, the whole remaining portion of the ingot was sound and solid. If an ingot of ordinary carbon steel were sectioned longitudinally and compared with a high-silicon ingot treated in the same way, just under the skin of the carbon steel innumerable small cavities or blow-holes would be found, while the high-silicon ingot would be practically free from these. The sound surface of the silicon-steel ingot tended to produce a denser surface on the finished rail, and he was also of opinion that there was less segregation in silicon steel than in ordinary steel of similar composition. From the metallurgical point of view, he would certainly expect that Sandberg silicon rail-steel, when compared with ordinary steel containing the same percentage of carbon, etc., would give distinctly better results in respect of wear; and the same remark applied to the corrosion, since all theoretical considerations and laboratory experiments pointed in that direction; but in view of the somewhat different opinions held by various engineers as the result of their own wide experience, both these questions called for further systematic investigation. He could not help thinking that the different results obtained were due largely to some important variation in the conditions under which the different trials had been made. It was not sufficient to lay down high-silicon rails for comparison with ordinary open-hearth or Bessemer rails unless precautions were taken to ensure that the rails were as nearly as possible identical in composition in all respects except silicon. Comparison of a high-silicon low-carbon rail with a low-silicon high-carbon or high-manganese rail would obviously give very misleading results, as silicon was not to be used as a substitute for carbon, but must be used in conjunction with the highest percentage of carbon which could be employed safely. Mr. Willox's comparisons were open to very serious criticism in this respect, for on p. 85 high-carbon silicon rails made by the basic open-hearth process, and containing 0·74 per cent. to 0·69 per cent. of carbon, were compared with high-silicon Bessemer rails containing only 0·45 per cent. to 0·39 per cent. of carbon. It was probable in any case that the open-hearth rail would have given better results than the Bessemer rail had they been identical in composition; but it was quite certain that the difference would have been far less than was shown by the recorded results had the carbon been approximately the same in each; and the credit given to silicon for the superior behaviour of No. 1 rails should undoubtedly be shared by the high carbon. Similar remarks applied to the comparison between No. 1, No. 3, and No. 4, although to a smaller extent. The only rails which could fairly be compared were Nos. 3 and 4, the basic open-hearth titanium rails and the basic open-hearth ordinary rails. As no doubt most railway-engineers were aware, titanium rails were tried in America several years ago and great advantages were claimed for Mr. Harbord.

M 2

Mr. Harbord. them, but as Mr. Harbord had found it extremely difficult to obtain reliable information, he had got one of the leading British railway-engineers to order 100 tons of these rails, and to allow him to have 20 tons at cost price for experimental purposes. In order to obtain as far as possible comparative results, four consecutive heats of steel from the same furnace were made, two with titanium and two without, the proportions of carbon and manganese being kept as nearly the same as possible. He asked Mr. Willox and also Mr. A. R. Cooper, M. Inst. C.E., of the Metropolitan District Railway, whether they would give these rails a trial, and both gentlemen readily agreed to do so, subject to the rails fulfilling all tests required by their specifications. Mr. Willox was just arranging to try some high-silicon rails, and he kindly put these titanium and ordinary open-hearth rails down for comparison under the same conditions. Mr. Cooper laid some on the Metropolitan, and Mr. L. R. Wood also put some on the Great Western Railway. Mr. Willox had given his results, and Mr. Cooper's results generally completely confirmed the results obtained by Mr. Willox, that no practical difference between the titanium steel and the non-titanium steel in the life of the rail was apparent, and so far as these experiments showed, no advantage was derived from the addition of titanium. Mr. Harbord noticed that Mr. Willox gave the drop tests for titanium and ordinary basic open-hearth rails No. 3 and No. 4 only on the whole rail, but drop tests had also been made on crop ends between 3-foot bearings. He personally saw these tests made and recorded the results, and he believed he had sent a copy of them to Mr. Willox: they were now included to make the comparison of the drop tests between No. 1 and No. 2 sets of rails more complete.

TESTS ON CROP ENDS BETWEEN 3-FOOT 6-INCH BEARINGS.

No. 3 Basic Open-Hearth Titanium.

Test No. 1.

25-foot drop on top of rail	3·45 inches
25 ,, ,, base ,, ...	back straight
25 ,, ,, top ,, ...	3·45 inches
25 ,, ,, base ,, ...	twisted

Test No. 2.

25-foot drop on top of rail	3·55 inches
25 ,, ,, base ,, ...	straight
25 ,, ,, top ,, ...	3·60 inches
25 ,, ,, base ,, ...	straight
25 ,, ,, top ,, ...	broke

Mr. Harbord.

Test No. 3.

25-foot drop on top of rail	3·55 inches
25 ,, ,, base ,,	straight
25 ,, ,, top ,,	3·50 inches
25 ,, ,, base ,,	straight
25 ,, ,, top ,,	twisted

Test No. 4.

25-foot drop on top of rail	3·50 inches
25 ,, ,, base ,,	straight
25 ,, ,, top ,,	3·50 inches twisted

TESTS ON CROP ENDS BETWEEN 3-FOOT BEARINGS.

No. 4 Ordinary Basic Open-Hearth.

Test No. 1.

25-foot drop on top of rail	3·95 inches
25 ,, ,, base ,,	straight
25 ,, ,, ,, ,,	3·95 inches
25 ,, ,, top ,,	broke

Test No. 2.

25-foot drop on top of rail	4 inches
25 ,, ,, base ,,	straight
25 ,, ,, ,, ,,	3·70 inches
25 ,, ,, top ,,	broke

Test No. 3.

25-foot drop on top of rail	3·90 inches
25 ,, ,, base ,,	straight
25 ,, ,, top ,,	3·80 inches
25 ,, ,, base ,,	straight
25 ,, ,, top ,,	4 inches, twisted too much for further test

Test No. 4.

25-foot drop on top of rail	3·85 inches
25 ,, ,, base ,,	straight
25 ,, ,, top ,,	3·60 inches
25 ,, ,, base ,,	straight, twisted too much for further test

The process of manufacture and the influence of the size of the ingot were referred to by Mr. Willox, who pointed out correctly that the open-hearth process gave greater control during the process of manufacture and enabled steel of more regular composition to be produced than the Bessemer process. Mr. Harbord believed this would be admitted by all metallurgists; the great extension of the basic open-hearth process in England and on the Continent showed that many steel-makers also realized the advantages of the open-hearth process. With regard to the

Mr. Harbord. size of the ingot as affecting the quality of the steel, there would probably be more divergence of opinion, since the larger the ingot, and consequently the slower the cooling, the greater must be the opportunity for segregation; the difference in the amount of segregation between a 4-ton ingot and a 2-ton ingot was, however, far less than was generally supposed—as had been shown by dividing ingots longitudinally down the centre, and taking drillings at regular distances of 2 or 3 inches right across, and from top to bottom. In any case, if large outputs were to be maintained and modern mills to be worked at their full capacity, Mr. Harbord feared the larger ingot had come to stay; and if engineers insisted on having their rails rolled from smaller ingots they would have to pay a higher price. It not only meant a smaller output for the steel, but also—as each ingot, whatever its size, had to be cropped top and bottom—the scrap from two small ingots was greater than from one large one. It was extremely difficult to state what composition of rail was best suited to meet the conditions of the modern railway; but general experience seemed to indicate that in England the standard rail-specifications were too low in carbon, while in America they had been too high, and that the English percentage of carbon could generally be increased safely to about 0·6 per cent. for open-hearth steel, especially with the low phosphorus and low sulphur contents which steel-makers were now able to supply. Under certain conditions of traffic this carbon might safely be increased to 0·7 per cent., whilst under other special conditions it might be desirable not to exceed 0·55 or even 0·5 per cent. In the case of Bessemer steel, it would be desirable to specify rather lower limits of carbon for work under similar conditions. Given such steel, especially if silicon were added as was done by Mr. Sandberg to ensure soundness, the combination of hardness, toughness, and soundness thus produced, particularly when such impurities as phosphorus and sulphur were almost completely removed, would, he believed, considerably improve the quality of rails and increase their life under service conditions. The results obtained with manganese-steel were of great interest and might be very important, as it was this combination of hardness and toughness which all had been trying to obtain. It now rested with the metallurgist to produce this or a material with similar properties at a cost at which it could be used to a much larger extent by British railways. The results of Mr. Willox's experiments with manganese-steel would, from the economic point of view, be awaited with great interest.

With regard to Mr. Sellon's Paper, whatever the cause of corrugation might be, it certainly was not due either to variation in the composition of the steel or to local hardening set up during the process of rolling. The regularity of the corrugations made it impossible to conceive that variation in composition was responsible, as whatever variation there might be was not distributed in this regular manner. The fact that when corrugations were ground out they appeared again also refuted the suggestion that rolling was responsible. If a corrugated rail were tested on its running-surface for hardness, distinct difference would be found between the hollows and crests, but this was due not to variations in hardness in the original rail, but to the hardness produced by cold rolling by the wheels of the rolling stock. If a corrugated rail were sectioned longitudinally through the head for a considerable length, and the sectioned surface tested for hardness, no appreciable difference would be found to exist between the metal at the hollows and crests —at all events, Mr. Harbord had never discovered any. Some time ago he examined a long piece of rail sectioned in this way which was exceptionally badly corrugated, but he had failed to detect any variation in hardness. He was referring more particularly to railway-rails, as he had not examined many tramway-rails in this way. He gathered that the general opinion of engineers was that although rails of a certain degree of hardness might show less corrugation than other rails, corrugation was produced by a number of causes, some of which became active under some, and some under other conditions. At present, opinion seemed to be divided as to whether a very hard, medium hard, or soft rail gave the best results; or, at all events, the degree of hardness required had not been determined. Until the engineers had determined definitely by systematic experiments the approximate degree of hardness they required, he feared the metallurgist would be of little assistance. If, however, they would determine what was required, the steel-maker could give them rails of any degree of hardness or softness necessary. There would be a little more difficulty in rolling a very hard rail, and the cost might be slightly higher, but practically the hardness would be limited only by requirements for bending and drilling. If, however, engineers decided to use harder steel for tram-rails, they must modify their drop tests, as it would not be possible to supply tram-rails with, say, 0·75 per cent. of carbon with the same ductility as rails containing only 0·5 per cent. In view of the entirely different conditions prevailing on tramways as compared with the ordinary railways, a much harder and less ductile material could safely be used, and it was absolutely unnecessary to specify anything approaching such severe drop and other tests as were essential for ordinary rails. He would like to suggest Mr. Harbord.

Mr. Harbord. that some of the committees which were investigating this important subject should consider the advisability of carrying out a systematic series of experiments with rails of known composition, to determine definitely the rail which resisted corrugations most effectively; and he was sure that if this were done valuable information would be obtained, and steel-makers and metallurgists would be very pleased to co-operate and do everything possible to facilitate the investigation,

Mr. Hollingworth. Mr. E. W. HOLLINGWORTH thought that the following details of some corrugations which had appeared in paving-slabs at Ramsgate Harbour might be of interest as an example of an action similar to that which caused corrugations in tramway-rails, taking place under very different conditions. The corrugations, which were very pronounced in the York-stone slabs 7 inches thick, and were visible in the granite coping 15 inches thick, were caused by two-wheeled barrows, without springs, used in discharging block ice. These barrows had oak sides strapped with iron, and cast-iron wheels 11 inches in diameter. The corrugations formed in both stone and granite were of between 5 and 6 inches pitch from crest to crest, and were deepest at the joints, where deep grooves had been worn in the granite. The flanges of the wheels were gradually knocked to pieces, and evidently the corrugation was due to impact and not merely to increased pressure. The vibration was set up by a jerk at each joint, and its frequency, compared with that given for a tramway, happened to be approximately in the ratio of the moduli of elasticity of timber and steel.

Mr. Holt. Mr. R. B. HOLT, of Leeds, considered that the wear of rails on electric tramways was influenced to a considerable extent by the design and construction of the rolling stock. In the case of electric railways the principal factors resulting in corrugation, battering, and irregular wear were the method of suspending the motors, small wheels, and the application of power to one extremity of the axles, to which must be added the frequent use of powerful wheel- and track-brakes and the application of brake-sand on one rail only. Tramway practice also confirmed Mr. Willox's experience in regard to the diameter of wheels; tram-car wheels varied in diameter to a considerable extent after a very short period of service. In Belfast it was hoped that this particular trouble would be overcome by the introduction of pinions and gears at each end of the motors; whilst at Huddersfield, cars were being equipped with differential gears on each driving-axle, with very satisfactory results. Battering was well known on tramway-rails, but it was not such a source of trouble as corrugation; the metal extruded across the rail-tread and broke away. Another curious case of battering was where the entire tread of the rail, after having become very badly battered, had arched; in this instance, which was one peculiar to tramway-rails, the arching was due to piping. During the past 6 years more than 7,000 tons of Sandberg high-silicon steel rails had been used on the Leeds tramways, and it was worthy of record that so far there had been no indications of battering and no corrugations had had to be ground from rails of this quality. From actual experience with such rails in Leeds, it was safe to assume that the effective life of the rail would be extended by not less than about 30 per cent. With regard to the question of rail-corrugation, Mr. Sellon observed that none of the ingenious theories advanced, presumably by the investigating bodies referred to, had been found to be both comprehensive and convincing as to the general cause of the trouble, and no remedy had been found. Mr. Holt felt that these statements should not go unchallenged. It was true that it was not yet possible to indicate precisely the exact cause or causes of rail-corrugation; but recent investigations had established very clearly the fact that the source was not inherent in the rail, although some rails were more susceptible to the corrugative influence than others. Experiments made by the Municipal Tramways Association showed that it was possible to produce, upon perfectly true rails, paint-marks having exactly the same appearance and measurements as actual corrugations, the paint being applied to the wheel-treads while the car was travelling at about 12 miles per hour. It was not found possible to reproduce these counterfeit corrugations at will; but many records were obtained in different positions and in different towns. The foregoing fact, and the fact that corrugations appeared upon all kinds of track and overhead material, were sufficient to dispel the popular belief that the rolling-mill was the responsible agent. Further experiments made by the Association had proved conclusively that all car-wheels varied in diameter, that slip and skid were continually taking place in each revolution of a wheel, and that pure rolling motion scarcely ever occurred. There could be no doubt that the evil could be mitigated to a very considerable extent by the use of rails of superior quality; and in Leeds and on many other tramway systems the use of high-silicon steel had resulted in the confinement of the scourge to the faintest markings, or the development had been retarded to such an extent as to afford appreciable relief. Mr. Holt was of the opinion that it would not be possible to obtain a more satisfactory steel than the Sandberg steel for this

Mr. Holt.

Mr. Holt. purpose at a reasonable cost; and that the real solution of the difficulty lay in the questions of car-design, wheel-diameters, the method of applying the power to the axles, and probably in the introduction of differential gears, as was being done at Huddersfield, with a view to neutralize the tendency to slip and skid.

Mr. Jackson. Mr. H. JACKSON observed that Mr. Sellon's general conclusion on the cause of corrugation appeared to be that it was due to cold rolling. He did not explain why the corrugations started, but suggested that rails which were harder or had a higher elastic limit would obviate or diminish the trouble. Using assumptions somewhat in accordance with Mr. W. Worby Beaumont's figures (published before his experiments with the London County Council car) for the area of contact between a tram-wheel and rail, Mr. Jackson had investigated the direct stress on the head of a tram-rail. With a static load this appeared to be in the neighbourhood of the elastic limit. When, therefore, the dynamical action described by Mr. Willox as "battering" was taken into account, it would be seen that Mr. Sellon's general conclusion was supported. In addition to this, however, a contributory cause to this dynamical action, and through it to the rail-corrugation and wear, appeared to lie in the form of the standard tram-rail and the method adopted in laying. In a particular length of straight tramway-tracks laid under Mr. Jackson's superintendence, an instance of corrugation occurred very shortly after the rails were laid. While the work of construction was proceeding, several rails were unfished and turned up. The concrete underneath, which had been laid and packed after the rail was fixed, was found to be low for about 1 inch in width at the middle of the rail. On this being discovered, special care was taken to ensure proper packing in the adjacent lengths of rails. When cars were run over the track, corrugations commenced on the rails which had not been taken up and re-packed, but they did not occur on the portion where special precautions had been taken. This dynamical action was known to lead to excessive wear at the joint of the rail which was being approached by the car. Mr. Jackson considered that when looking for a remedy for corrugation and excessive wear, raising the elastic limit of the steel must not be relied upon alone. The manner of support was equally important, and there was also a third matter which demanded very careful attention. The present standard-section rails had a thin web and a broad flange. It seemed probable that under load the edges of this flange did not press on the concrete foundation at all. On the contrary, the edges were in all probability actually forced upwards by the pressure of the web. One result of this was the lifting of the sets or paving-blocks alongside the rail, leading—particularly where the support under the middle of the rail was not so good as at the sides—to the dynamical action referred to above. While the paved street-surface had to be maintained it was hopeless to expect that the load from the wheel could be distributed over a long length of rail, as was the case with the sleeper construction on steam railways. To rely wholly upon the raising of the elastic limit of the steel material of the rail would, in his opinion, lead to disappointment. The dynamical conditions introduced—and, from a practical constructional point of view, almost unavoidably introduced—by the present method of construction would cause the stress to go beyond the elastic limit in even the hardest steels. Still, half a loaf was better than none, and the harder steels might help. Mr. Jackson.

Mr. A. S. Keith, of Leeds, observed that, as a manufacturer of Bessemer basic steel rails, he had but little to add to Mr. Willox's Paper, except to express regret that a test of rails of that class of steel had not been made also, since so much of it was used in the north of England; he had yet to learn that Bessemer basic steel, when carefully made, was inferior in test-results or in wear to any open-hearth steel, or that it could be debited with any larger percentage of breakages. He was pleased to find that Mr. Sellon did not lay the onus of corrugation on the manufacturer, and he believed it was now generally recognized that no mechanical treatment, during the process of rolling rails, was productive of corrugation. He believed the action to be due more to the softness of the rails made during the earlier history of the tram-rail trade, and to there being no definite knowledge of the relationship of the hardness of the tire to that of the rail. The question of the size of ingot used in rolling tram-rails was not affected so much as in railway-rails, as it was very unusual to roll more than two 45-foot lengths or one 60-foot length at one time; if the section was to be maintained within the limits allowed by the British Standard specification, this practice would have to be adhered to. After the abandonment of chilled cast-iron wheels, the question of the hardness of the tire had probably been arrived at only by successive increases in the hardness, until the steel in these was specified to be much harder than the rail. A very hard wheel with a soft or even moderately hard rail was certain to result in excessive wear of the rail. On the other hand, a soft wheel might be even worse; flats would be caused on the wheel, resulting in hammering on the rail, and possibly producing corrugations. He considered that the balance of hardness between the rail and the tire was an important factor. When it was remembered that the tenacity often specified for tires was 65 tons per square inch, Mr. Keith.

Mr. Keith. and that for rails a minimum of 40 tons per square inch, there was reason to believe that the rail must suffer; and unless there were more agreement between those responsible for the maintenance of the cars and of the track, there was bound to be this recurring trouble. He did not think the tenacity of the tire would be reduced, and the question arose how far the hardness of the rail could be increased. During the past 10 years his firm had made much harder tram-rails, of a tenacity of 48 to 60 tons per square inch, with very good results, but they had always obtained the sanction of the engineer to a much less severe tup test. In the harder rails thus produced, considerably more care had to be taken in straightening, holing, handling, and curving, but a limit to this hardness had been reached unless the purchaser was prepared to pay a much higher price for special steels. Mr. Keith considered also that the oscillating motion of a car due to slackness of the wheel-gauge, variation of the wheel-diameters, and vibration on the springs due to the very short wheel-base often seen on cars, were conducive to the production of corrugation; and, as Mr. Sellon pointed out, the concentration of the load on such a small area of contact produced a strain beyond the compressive elastic limit of the rail.

Mr. Mattinson. Mr. HENRY MATTINSON observed that the chief value of Mr. Willox's Paper lay in the fact that his evidence was founded on the positive result of working-conditions and not upon implied conclusions based on academic premises. To obtain rails of greater wearing-capacity was of special importance to tramways, for while the cost of the rail was less than 20 per cent. of the total charges for construction, yet it alone determined the life of the whole track. In 1907 a trial of high-silicon steel rails was made in Manchester by relaying Oxford Street with such rails, and at about the same time Market Street was relaid with ordinary steel rails. Both these roads had previously sustained a traffic of $2\frac{1}{2}$ million cars during a period of 6 years before their reconstruction. The average chemical composition of the rails was:—

	Oxford Street. High-silicon steel.	Market Street. Basic Bessemer steel.
Carbon	0·50	0·49
Manganese	0·78	0·82
Silicon	0·34	0·05
Phosphorus	0·06	0·06
Sulphur	0·057	0·052

At the 31st March, 1914, they had carried 2,830,000 and 2,470,000 cars respectively during the 7 years they had been laid. Market Street now required relaying, whilst Oxford Street had safely 2 years more life remaining, an increase of at least 25 per cent. Since 1907 about 10,000 tons of high-silicon rails had been used in Manchester, with gradually improved qualities, as the following details of a recent rolling would suggest :— Mr. Mattinson.

BASIC BESSEMER STEEL (LEEDS STEEL WORKS).

Carbon	0·54
Manganese	1·06
Silicon	0·26
Sulphur	0·06
Phosphorus	0·06

Tensile strength, 54·8 tons per square inch; 18 per cent. elongation on 2 inches; contraction, 23 per cent.

Deflection (span, 3 feet 6 inches; tup, 1 ton; drop, 15 feet), first blow, $\frac{7}{8}$ inch; second blow, $1\frac{5}{8}$ inch; no sign of fracture.

Brinell's impression test, 3·3 millimetres, with 50 tons on 19-millimetre diameter ball.

The record on pp. 87 and 88 of a high-silicon rail that had been laid 5 years and had had only $\frac{1}{8}$ lb. per yard worn away by a traffic of 1,121 million tons was so remarkable that Mr. Mattinson had been desirous of investigating the subject further, and by the courtesy of Mr. Willox he had been afforded an opportunity to examine the steel microscopically. The result was extremely interesting, not only confirming the Author's statement on p. 88 that the "composition was almost ideal," but, what was even more important, also indicating that the "structure" was equally good. Micrographs taken at points about $\frac{1}{8}$ inch and $\frac{1}{2}$ inch below the middle of the rail-table, and about $\frac{1}{8}$ inch and $\frac{3}{8}$ inch from the inner edge of the rail indicated a remarkably uniform structure of closely laminated pearlite, scarcely visible at 1,000 diameters, but clearly defined at 1,500 diameters; of ferrite there was practically no trace. The structure in the samples from the middle of the head was finer than in the portions at the edge, and had not been subjected to the distortion evidenced in the latter. The steel was a finely lamellar eutectic pearlite, although the analysis would not quite suggest this. The fact that this rail stood alone among others of the same rolling, pointed to a conjunction of correct composition, heat-treatment, and cooling, the attainment of which was the desire of all engineers. The relation of these factors was not definitely known, and Mr. Willox had given further encouragement to the efforts to elucidate them by his statement of an ideal rail in practical use. Mr. Mattinson would draw attention to the enormous aid to users of

Mr. Mattinson. steel rails provided by the metallurgical microscope in the development of steel. The chemical analysis was essential, as showing of what ingredients the material consisted, but of even greater importance was the manner in which these ingredients crystallized—so many were the forms they could assume, and so delicate were the factors affecting the several allotropic modifications of the iron-carbide alloys. The furnace treatment, the ingot cooling and reheating, the rolling-temperature, and particularly the final cooling —both as to temperature and rate of cooling—were all factors resulting in modifications of the structure which were not revealed by chemical analysis but were clearly disclosed by the microscope. What had been done once could be done again, and Mr. Willox had afforded an example of steel for rails which it would be the ambition of all engineers associated with their use to repeat.

Mr. Millar. Mr. A. Millar considered that it was remarkable how baffling and perplexing the subject of corrugations had proved to the many engineers in various countries who had devoted considerable time and attention to the subject during the past 10 years or more. A great many theories had been submitted to account for corrugations, and some of the remedies suggested had met with a certain measure of success in individual cases; but where general application had been attempted, the limitation of each particular remedy had been quickly realized, and the supporters had been obliged to admit that there were many phenomena connected with corrugations that could not be accounted for by the particular theory put forward by them. From this it might be inferred that corrugations were not due to any particular defect in either the design or manufacture of the rails or the rolling stock, but to a combination of circumstances; and the problem would be solved only by following up such of the theories as had been shown to have a practical bearing on the subject. A good deal of stress had been laid, quite properly, on the importance of obtaining harder and more reliable rails, and it had been implied that, if this course were followed, corrugations might cease to appear. This alteration by itself, however, would not have the desired effect, as even in cases where the hardest materials had been used, such as manganese-steel, corrugations had appeared in tramways, although not nearly to the same extent as with ordinary steel rails. He suggested that the section of the rail had also an important bearing on corrugation. With regard to the lateral spreading, or detrusion, which appeared in the rails after they had been in use some time, as a contributing cause of corrugation, this lateral detrusion was very general in tramway systems, but the adoption of a rail with a rounded head, had done much to lessen the detrusion, and, as a result of this, the corrugations also. It was very common to find that even after a new line had been in service for a year the load-area of the rail-table was confined to a width of $\frac{1}{2}$ inch or less, next the gauge-point, with the result that the compressive elastic limits of the metal had been exceeded locally, with extensive detrusion. In places where round-headed rails had been laid down to replace rails of the standard section the load-area had been found, after a short period, to extend across the rail-table, and lipping-over of the metal at the gauge-point had been very small, while the corrugations had not been nearly so numerous or so marked as in the case of rails of standard section. Further evidence of the destructive effect of unequal loading had been obtained, in the case of the London County Council tramways, by plaster casts and by a long series of very careful measurements taken by a micrometer gauge of special design, ensuring absolute accuracy in obtaining the wear of the rail-table, at intervals of 6 months; and from these it had been ascertained, that the wear in some cases during the first 12 months was very much greater than during any similar ensuing period, this greater wear being due chiefly to the load coming on a narrow strip near the gauge-point. The introduction of welded joints in recent years had proved the fallacy of the theory, once widely held, that corrugations were mainly attributable to imperfect joints, as corrugations of considerable magnitude were to be found on routes where only welded joints were in use. He considered that, as corrugation had been discovered under such widely differing conditions in the composition and form of rails, it pointed to the need of greater attention being devoted to improving the present designs of rolling stock for electric tramways and railways. The seriousness of the question of corrugations was shown by a tramway authority, such as the City of Glasgow, confessing that rail-corrugations cost their undertaking £10,000 a year, and by many other tramway authorities admitting a similar state of affairs. He suggested that all large electric railway and tramway undertakings should set aside and keep under observation one route, to be selected after the service had been working for some time, on which corrugations had appeared. Before the line was run on an experimental footing, all existing corrugations should be ground out, and records should be kept, at different points, of the extent and form of new ones. Rails of different composition and form could be tried on various parts of the experimental routes, with different types of cars. If authorities made common cause in the matter a great variety of combinations could be Mr. Millar.

Mr. Millar. tested, and the solution of this very vexed question would be brought nearer. On certain routes in London high-silicon rails had been laid, and with these had been laid ordinary rails for the purpose of comparison. Readings had now been taken at intervals of 6 months, during a period of nearly 3 years, and in all cases but one the results had been in favour of high silicon. The advantage, however, had been very small, amounting to something between 1 and 3 per cent. In the case where the result was in favour of the ordinary steel rail the difference was about 8 per cent. At this place the high-silicon rails had been laid on a gradient of 1 in 11, and it must be regarded as a grinding rather than a rolling test, as the rails under test were on the lines used by descending cars, and all cars descended with the magnetic brake on, thus subjecting the rails to a very severe test.

Mr. Mittelhausen. Mr. CHARLES MITTELHAUSEN observed that all would appreciate the vast amount of patient investigation which had been carried out by the various tramway associations and officials individually, with regard to corrugation questions, but he did not believe that the causes of this complex phenomenon would be traced to their origin on an ordinary street-tramway. It was not possible to keep constant, over a period sufficient to arrive at definite conclusions, many of the conditions believed to be favourable to the production of embryo corrugation. If the London County Council subway on the Embankment could be dedicated exclusively to the study of this elusive subject, there would be considerable hope of solving the problem there; unfortunately, however, owing to the exigencies of the traffic, such a course was not feasible. Under the circumstances, the only hope of success seemed to lie in the construction of an experimental line, which would have to be protected against weather, and in which the degrees of moisture, the quantities of grit, brick, and earth, and any of the other factors which jointly or severally were alleged to be responsible for corrugation, could be kept constant or varied at will. Such a line should embody those features which were found most favourable to the production of corrugation on ordinary tramways; e.g., a long-radius curve on a gradient, a short-radius curve on the level, etc. This scheme would naturally be costly, and would probably require international cooperation to carry it to a successful issue. In view of the great expense of grinding-out corrugations, and the still greater expense due to the reduced life of the rails, paving, etc., and damage to rolling stock, a considerable outlay having reasonable hope of success would be justified. As, however, a definite conclusion was hardly likely to be arrived at for some years, everything possible should be done to mitigate the nuisance in the meantime. He observed that high-carbon rails were generally recommended, and he believed that they certainly postponed the evil day. He could not, however, confirm Mr. Sellon's experience, that rails containing more than 0·6 per cent. of carbon were immune from trouble. Indeed, he had found that rails containing 0·7 per cent. of carbon corrugated within 3 years under fairly light conditions of service. He would also suggest that in the present state of darkness on the subject, the rail-groove could with advantage be rolled deeper, so that when grinding became necessary, the wheel-flanges would not bottom as at present; for when that happened it was not long before the wedging action of the flange widened the rail-groove to a dangerous extent, and the rail had to be renewed prematurely. It was not his intention to attempt to apportion the blame between the rolling stock, the rolling-mill, and the road-bed; but he thought the following special cases were instructive, and that with a little more spring in the road-bed and cars much relief might be obtained. In September, 1913, he inspected a tramway laid on a public highway on transverse ballasted sleepers, filled to the level of the rail-table with ordinary macadam. After 16 years no sign of corrugation was visible, but in other parts of the city, where ordinary concrete foundations were used, corrugation was frequent 9 or 10 years ago. The same cars ran over both roads. He was fully conscious of the difficulty of making a satisfactory resilient rail with the ordinary type of wood or granite paving, but he did not believe this to be unsurmountable. The second example occurred on the Bexley Urban District Council tramways. In 1908 a portion of this system, which had then been worked for 5 years, and which was free from corrugation, was leased to the Erith Urban District Council, who supplied their own cars, and in a few weeks corrugations appeared. At the end of 12 months the lease expired and the Bexley cars resumed running, and in 14 weeks the corrugations disappeared. In 1910 the Erith cars again replaced the Bexley cars, and corrugation reappeared in 8 weeks. The cars were very similar in weight, equipment, speed, and wheel-diameter, the chief points of difference being that the Bexley cars had chilled-iron wheels, $4\frac{1}{4}$-inch axles, and improved springs, while the Erith cars had steel tires and $3\frac{3}{4}$-inch axles, and were somewhat dead on their springs. Had it been possible to change the cars once more, he believed that the result would have been very instructive. In this case the immunity from corrugation was apparently due to greater resiliency of the car, and in the former case to that of the rail. Considerable improvement in the drive of the cars was

Mr. Mittelhausen.

Mr. Mittelhausen. secured by the use of a pinion at each end of the armature-spindle. This arrangement was introduced by Mr. A. Blackburn, of the Belfast City tramways, who, although he did not ascribe the comparative freedom of Belfast from corrugation entirely to this cause, considered it very helpful, since he obtained a square drive and abolished the disagreeable swing which the single-pinion drive produced, especially if the wheels were at all slack to gauge. It had been deplored that it was necessary to keep the centre of gravity of a tramcar so low, as it gave too little room for satisfactory spring. This was perfectly true, but in double-decked cars with heavy top-loads the factor of safety against toppling on curves was painfully small on narrow-gauge lines, and even on the 4-foot 8½-inch gauge several serious accidents had occurred. Apart from this, an extra step would be required between the platform and the ground, which would certainly cause delay in loading. Some attempts were made in early tramcars to take part of the weight of the motor off the axle. The remedy had proved worse than the disease in that particular design, for the pinion jumped out of mesh with the spur-wheel, and eventually the spring arm had to be bolted up solid. Probably a better design with limiting stops might save many dished joints, if not corrugations. As was to be expected, the Papers had still left uncertainty as to the genesis of corrugation, but if they should lead to the problem being dealt with on a suitable experimental track, the Authors would have rendered a great service to the industry.

Mr. O'Brien. Mr. E. O'Brien observed that his experience of rail-corrugation was limited to one instance of the phenomenon, which had occurred at a spot on the railway between Liverpool and Southport. The corrugation there was distinct, but not strongly marked, and extended over about ¼ mile of track; it had existed in the days of steam-hauled traffic, and still existed after 10 years of electrical working. In this case, as in many others, the line ran over a bog just at the point where the corrugation occurred. The inconclusive nature of the evidence collected up to the present would lead, by a process of elimination, to the conclusion that corrugation depended on the nature of the true foundation of a railway or tramway, and not merely on the nature of the upper 4 feet, or even 10 feet of road-bed. He suggested that a vibratory action in the earth caused by the passage of traffic was communicated to the rail, which vibrated sympathetically. At the nodes the rail was not affected, and ordinary wear appeared at these points; the bright spots were midway between the nodes, and were due to the high momentary intensity of pressure caused by the movement of minute range but very high frequency. Perhaps this vague guess might lead some more mathematically-minded member to formulate an exact theory. Mr. O'Brien.

Mr. J. A. Panton, of Liverpool, observed that Mr. Willox admitted that excessive wear of the rails was due to the dead weight of the motor on the axle, and to the method of driving that axle bringing about unequal wheel-diameters, which, in turn, destroyed the permanent way, especially on curves, with varying degrees of intensity, according to the elasticity of the track. That being so, why was not the original cause remedied, instead of an attempt being made to overcome the effects produced by that cause on the rails? Why adopt expensive permanent-way material and crossings to resist a known defect in rolling-stock construction? Considerable success had already been attained in overcoming this defect, the cost being a negative quantity in comparison with Mr. Willox's recommendations, especially when consideration was given to the expense of relaying tramway-tracks throughout the country to meet the difficulty. Having admitted that Sandberg rails corrugated, why persevere further? Mr. Willox's comparison of the life of rails on main lines worked by steam with that of rails used for suburban electric traffic was somewhat misleading without a statement of the ton-mileage over these lines during the period referred to. Secondly, the comparison between main-line steam trains rolling smoothly along a straight track and suburban electric trains with high acceleration never fully extended before heavy retardation took place under the most trying conditions of unlimited crossings and curves required further consideration. It would be interesting if Mr. Willox would state the wear of a straight length of track composed of ordinary rails on a suburban electric service when full acceleration had taken place, together with the tonnage passing over it in a given period, and compare this, say, with a similar suburban steam service. Mr. Panton would expect the difference in rail-wear to be comparatively small, and to be due mainly to the difference between the methods of driving a number of live axles and driving a locomotive, and to the "hunting" effect of an electric train compared with the pull of a locomotive. Mr. Panton.

Mr. Reginald Peters observed that Mr. Sellon's Paper conveyed the impression, doubtless intended by its author, that he had small faith in the various suggestions reviewed as to the primary cause of rail-corrugation. So far as Mr. Peters had examined these corrugations on an English railway, the outstanding feature was a regularity of pitch in each case, or, more often, a periodic change Mr. Peters.

Mr. Peters. of pitch between fairly definite limits. On this account theories which merely involved irregularities in the original form, composition, or hardness of the rail were scarcely tenable. In the case of the first two it was at least improbable that the changes would always occur in more or less regularly periodic form. Mr. Sellon attempted to connect fluctuating hardness with some action of the mill-gearing. All rails from the same mill would then corrugate, if at all, in the same manner. There was no evidence of this. None of these theories alone explained the accentuation in use of the original slight variations. Mr. Peters considered that an analogy might be found between rail-corrugation, due to vibration of the wheel, the rail, or the road-bed, and the chatter of a machine-tool due to insufficient rigidity of the tool, the work, or the machine. Whilst there was a family likeness in all corrugations, each case appeared more or less to follow its own law. The types of railway rolling stock seemed too diverse to produce vibrations in unison, or if there were a tendency to do so, more consistent results would be expected. The rail itself might vibrate in the chairs, but again there was the pitch-variation to account for, and in any case this explanation would not apply to tramways, where the rail was supported continuously. On the other hand, there was the familiar tremor imparted to the surface of the ground by the passage over it of a heavy object. This might well be of a defined though complex periodic character, and, being imparted to the rail, might cause a series of beats upon the latter by the wheel. The marking was often decidedly accentuated towards the chair-centres, where the stiffness of the rail would be greatest. When the rail beat against the wheel the elastic limit of the metal would be exceeded; when the rail receded the pressure on it would be relieved and it would be subjected to a cold rolling action. Here might be traced the influence of the composition of the rail-metal, alluded to by Mr. Sellon. Where the nature of the metal was such that it did not respond to the process of hardening by cold rolling, corrugation would be retarded or even entirely absent. Given any situation where the average speed of traffic was fairly constant, and the rail-metal of such a character that its hardness was ready to change under differences of treatment—which variations would in turn tend to force succeeding vibrations into step—the formation of corrugations was no longer remarkable. More data were required to test the accuracy of the theory outlined above. If it should prove satisfactory, the cure of the corrugation difficulty would lie, as pointed out by Mr. Sellon, in the use of suitable steel for the rails.

Mr. W. H. SELLEW, of Detroit, Mich., observed that, as suggested by Mr. Willox, the effect of the rigidity of the track, and the large un-spring-borne component of the wheel-load generally found on electric railways, appeared to deserve careful attention in connection with the study of the wear of rails on such lines. Experience in America had been that the type of electric locomotive used on the Pennsylvania Railroad, with a high centre of gravity and carrying the weight on the springs, was much easier on the track than one in which the motors were mounted on the axle. The tendency in street-railway construction in America was towards a very rigid track, and these rails corrugated badly, in spite of the fact that the percentage of carbon was fully as high as that required for rails used on steam lines. On the latter little trouble was experienced from this source, and where corrugation existed it was generally to be associated with some peculiar condition of traffic or roadway, as, for example, on the Bessemer and Lake Erie Railroad, where many steel sleepers (**I** section) were used, and the traffic consisted of a dense movement of coal- and ore-cars of large capacity. Mr. Willox's reference to the resiliency obtained in the construction of the permanent way of the latest tubes of the London Electric Railways was especially interesting to Mr. Sellew, as some months ago he started an experiment to determine the effect of the resiliency of the rail on the pressure at the surface of contact of the wheel and rail. The experiment was not complete, and the work done had been of a preliminary nature. He enclosed a record of the results obtained so far.[1] Mr. Sellew.

Mr. S. A. STRICKLAND observed that the South Australian Government Railways commenced to use high-silicon rails in 1908, and up to the present time had purchased about 66,000 tons, the weights being 80, 60, 50, and 41 lbs. per yard. The steel was made under the supervision of the late Mr. C. P. Sandberg, M. Inst. C.E., and to his requirements with regard to chemical composition. During the same period the South Australian Government had also purchased carbon-steel rails to the tests required by the British Standard specification for flat-bottomed railway-rails. Comparative tests of the high-silicon against the ordinary rails had been made, the results of which might be interesting, as both kinds of rails were made at the same works and laid in a uniform curve carrying the same traffic. Both lots of rails, which weighed approximately 60 lbs. per yard, were made by the acid Bessemer process. They were weighed before being put into the road, and at Mr. Strickland

[1] In the Library Inst. C.E.—SEC. INST. C.E.

Mr. Strickland. subsequent intervals of 6 months. After the second six-monthly weighing, the anticipated life of the rails was worked out as:—

Silicon	7·38 years.
Ordinary	5·358 „

Taking into account the original cost of the two kinds of rails, and also the labour, the saving in favour of the former had been calculated at £29 per mile per annum—or about 27 per cent. Three further six-monthly weighings had now been made, and generally these confirmed the above figures.

Mr. Willox. Mr. WILLOX, in reply, observed that Mr. Fergusson suggested that the silicon in the rail-steel that he recommended for railway purposes might remain at 0·2 per cent., as silicon reduced elongation, which tended to brittleness. That was true, of course, as regarded silicon left in from the pig-iron, but in the silicon-steel on which Mr. Willox had made tests the pig-iron had first been freed from silicon, and then the necessary quantity had been added. The effect of this was certainly not to produce brittleness, as was proved by the severe punishment which the rails successfully withstood under the tup test and in wear. Mr. Fergusson's recommendation for good wearing tramway-rails, namely, silicon 0·25 per cent., which he suggested could be obtained at less cost than high-silicon steel, was somewhat misleading; steel with that percentage of silicon was virtually silicon-steel. If the suggestion of 0·25 per cent. silicon did not refer to added silicon, Mr. Willox thought no manufacturer would agree to make rails of such a quality of steel, and still less would a tramway-engineer be prepared to put them in track, as there would be no certainty of obtaining regularity in quality where silicon was left in from the pig-iron. Mr. Harbord's remarks were very gratifying as confirmation, from the metallurgical point of view, that high-silicon steel should give the superior results which Mr. Willox had obtained in practice. Mr. Harbord's suggestion that the true effect of silicon would be best demonstrated by testing rails of exactly the same composition, made by the same process, with only the silicon varying, was no doubt correct from an academic point of view, but from the practical—the railway-engineer's—point of view it seemed to Mr. Willox sufficient that high-silicon steel rails were not only able to withstand very severe tup tests but also proved satisfactory in the road in regard to wear and safety with higher carbon-contents than non-silicon rails. Mr. Mattinson, however, practically gave the comparison suggested by Mr. Harbord between the composition of high-silicon steel and ordinary steel.

The composition was almost identical, except in silicon, and Mr. Mattinson's experience in Manchester was that silicon-steel rails gave at least 25 per cent. longer life. Mr. Strickland's statement was an interesting comparison between the two qualities of rail, manufactured by the same process and by the same manufacturer, and taking into account the actual cost of the rails laid in the track and the annual saving in pounds per mile. So far as Mr. Willox knew, this was the most complete report and investigation made by any steam railway. He desired to thank Mr. Harbord for making the chemical analysis (p. 85) of the various rails tested. Mr. Willox.

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3 March, 1914.

ALEXANDER ROSS, Vice-President,
in the Chair.

The Council reported that they had recently transferred to the class of

Members.

Francis Aloysius Bald.
Charles Seager Berry.
Harold Thomas Creasy.
Benjamin Kington Finnimore.
John McFarlane Kennedy, B.A. (*Cantab.*).
Henry Gardiner Lloyd.
Richard Marion Parkinson.
James Douglas Kendall Restler.
Wilfrid John Abis Watkins.
John Burdett Willis.

And had admitted as

Students.

Trevor Dudley Hall Alderton.
Horace William Ash, B.Sc. (Engineering) (*Lond.*).
Sorab Dinshaw Bamjee, B.Sc. (Engineering) (*Lond.*).
Edward Ernest Barnard.
John Millar Boyd, B.Sc. (Engineering) (*Lond.*)
John Aldhelm Raikes Bromage.
Thomas Hubert Macartney de Burgh, B.E. (*Sydney*).
George Eric Cheslyn Callow, B.Sc. (*Manchester*).
Robert Downie, Jun.
Robert Dundas Duncan, B.Sc. (*Edinburgh*).
George Augustus Churchill Esdaile B.Sc. (*Manchester*).
John Sharman Franey.
Sydney Llewellyn Hall, B.Sc. (*Bristol*).
Arthur Raymond Marshall, B.A. (*Cantab.*)
Forster Herbert Martin Maynard.
Stewart Alexander Miller-Hallett.
David Ivor Phillips, B.Sc. (*Bristol*).
Will Pickstone.
Roy Evelyn Ponsonby.
Raphael Chevallier Preston.
Leonard Albany Ritchie.
Colin Scott Stuart.
John Amhurst Walter.