

Mr. R. PRICE WILLIAMS said since the Paper was written he had completed some additional experiments, at Mr. Kirkaldy's works, on the tensile and compressive strength of rails rolled from cogged and from hammered ingots, and also on steel rails which, previous to being punched, had been plunged, while hot, into water; and the results fully confirmed those previously given by the bending stress. The results of these later experiments showed that the limit of elasticity under the pulling stress was more than 12 per cent. higher in the cogged than in the hammered ingot rails, and that the limit of elasticity under thrusting stress was 5 per cent. in favour of the cogged ingot rails. Further, there were indications of greater toughness in the cogged ingot rails under the thrusting stress, the depression under weights of 100,000 lbs., and 150,000 lbs. per square inch, being 13 per cent. less.

SUMMARY of TABLE 12 (*vide* Appendix),
MESSRS. FOX and Co.'s STEEL RAILS.
Pulling Stress.

—	Elastic Stress per square inch.		Ultimate Stress per square inch.		Ultimate Extension per cent. of length.	
	Rail Top.	Rail Bottom.	Rail Top.	Rail Bottom.	Rail Top.	Rail Bottom.
Rails made from cogged ingots	lbs. 52,400	lbs. 52,750	lbs. 95,476	lbs. 99,805	7·9	9·2
Rails made from hammered ingots	46,650	48,950	100,878	101,695	15·8	15·4
Percentage in favour of cogged ingot	12·33	7·76

Thrusting Stress.

—	Elastic Stress.	Percentage in favour of Cogged Ingots.	Depression at 100,000 lbs. per square inch per cent.	Depression at 150,000 lbs. per sq. inch per cent.
Rails made from cogged ingots (Rail top.)	lbs. 58,000	4·97	3·4	14·0
Rails made from hammered ingots (Rail top.)	55,250		3·9	15·8

As regarded the steel rails, marked E, F, G, H on Plate 19, which before being punched had been quenched in water, the experiments showed that the limit of their elasticity under pulling stress was far higher when thus treated, the elasticity of the steel

taken from the head of these rails being, on an average, 17·61 per cent. greater. The increased toughness resulting from this particular treatment of the material was, moreover, strikingly shown by the results obtained under the thrusting stress, the limit of elasticity of the rails plunged while hot into water being 59,000 lbs. per square inch, as compared with 49,250 lbs. in the case of the untoughened rails, or about 20 per cent. in favour of the former. Again, the same favourable results were shown by the much smaller amount of the depression of the toughened rails under thrusting stress, the depression amounting only to 6·6 per cent. under a pressure of 100,000 lbs. per square inch, as compared with 9·4 per cent. in the rail which had not been so treated, showing 42·42 per cent. in favour of the material which had undergone this toughening process.

The average amount of carbon in all the steel rails of Messrs. Cammell and Co. was only ·174 per cent. for the A, B, C, and D rails, and ·179 per cent. in the case of the E, F, G, and H rails.

SUMMARY of TABLE 12—continued (*vide* Appendix),
MESSRS. CAMMELL and Co.'s STEEL RAILS.

Pulling Stress.

—	Portions from Rail Top.				Portions from Flange.			
	Elastic Stress.		Ultimate Stress.		Elastic Stress.		Ultimate Stress.	
	lbs.	Per cent. ¹	lbs.	Per cent. ¹	lbs.	Per cent. ¹	lbs.	Per cent. ¹
Rails plunged when hot into water (G, E, F, H.)	48,075	17·61	90,750	11·72*	53,250	16·08	92,555	13·78
Rails in ordinary state (A, B, C, D.)	40,875		81,225		45,875		81,342	

Thrusting Stress.

—	Elastic Stress.		Depression under 100,000 lbs. per square inch per cent.		Depression under 150,000 lbs. per square inch per cent.	
	lbs.	Per cent. ¹		Per cent. ¹		Per cent. ¹
Rails plunged when hot into water (G, E, F, H.)	59,000	19·80	6·6	42·42	20·5	21·95
Rails in ordinary state (A, B, C, D.)	49,250		9·4		25·0	

¹ In favour of cooled rails.

In the course of the discussion on his former Paper on Rolling Stock, exception had been taken to the average rate of depreciation assumed in the case of locomotive engines, which increased, according to his view, as the square of the time; his contention being, that while the rate of depreciation of some of the longest lived parts of the structure was tolerably uniform, many other parts were exposed to constant wear, where the rate of depreciation must necessarily be much more rapid, being probably as the cube of the time; but that the average rate of depreciation of all the parts would be a mean between these two extreme cases, a condition fulfilled by the ordinary parabolic curve. The means of practically testing the rate of depreciation of iron rails had, since then, fortunately presented itself, and he had been enabled, through the kindness of Mr. Johnson, M. Inst. C.E., Chief Engineer of the Great Northern Railway Company, to exhibit diagrams, Plate 20, showing the actual failures of guaranteed rails, and extending over periods of seven years. It would be observed, that the outline, showing the rate of failure of the rails of the 4,000 tons contract, Fig. 1, almost exactly coincided with his curve of average depreciation, which increased as the square of the time. The figures No. 2 and 3 showed the rates of failure in the other two contracts for guaranteed rails of 1,600 tons and 1,400 tons respectively. The curves in these cases indicated a depreciation increasing in a somewhat higher ratio than that of the square of the time. This afforded a strong confirmation of his view, that in all structures composed of different parts, and subject to wear, the curve of depreciation must necessarily be of the character described. Following out that idea, he exhibited a diagram (Plate 20), showing the value of 1 mile of permanent way, at successive periods, assuming the depreciation to increase as the square of the time, and the life of steel rails to be forty-two years. In this diagram the serrated outline showed the net value of the permanent way, before and after each renewal of the different parts. The curved line of average depreciation gave an exact average of the irregular serrated outline, and its mean ordinate occurred at about twenty years, or, in exact figures, at $\cdot 577$ of the longest life—at which period the permanent way would have attained its average value, viz., two-thirds of the first net cost, to which, of course, for purposes of valuation, would have to be added the scrap value of the materials. It consequently followed that the normal depreciation in 1 mile of permanent way was one-third of its first net cost.

With regard to the tests of the fish-plates, it would be seen that the bearings were 5 feet apart, and that the results were relative.

Mr. Kirkaldy had declined to test the rails with 2-foot bearings, thinking, and he thought correctly, that with bearings 2 feet apart it was impossible to get any useful result as to deflection or set: nor was it fair to consider rigid supports 2 feet apart as at all comparable with sleepers 2 feet apart. He was glad of the opportunity of expressing his obligations to Mr. Kirkaldy for the great assistance afforded him, apart from business considerations, throughout this inquiry.

Mr. MAY said a cogged ingot was, in truth, simply the reduction of an ingot to the size of the bloom—say from 12 inches to $6\frac{1}{2}$ inches square. Whether done with a hammer or by rolls it was still cogging. The only difference between rolling or hammering an ingot down to the bloom was that, in hammering, the result was an ingot with a rounded end, on account of the percussive force driving out the soft metal towards the end; and in the other case a bird's-mouth ingot, by drawing the metal over; the tensile strength and wearing properties were the same, whether the reduction was effected by hammering or by rolling. He did not understand what was meant by toughening by plunging into water. Steel with a sufficient amount of carbon was hardened by plunging into water; with less carbon it was made more resistant, but not tougher. As to punching and drilling, there was no difference in the results, except that in the punched rail there was sometimes a minute crack at the end which came out in the wear. Punching or drilling did not affect the actual strength of the rail.

Mr. W. B. LEWIS felt under great obligation to Mr. Price Williams for the mass of information he had collected, to which it seemed hopeless to attempt to add anything. But on one or two points he thought there was not material enough to form an accurate opinion. He had studied the table of analyses with great interest, but without much satisfaction. With reference to carbon, which was usually regarded as most important in the composition of steel, it was true that a rail with a minimum of carbon showed the best result. With rails 17 and 18 at the Maiden Lane tunnel the minimum of carbon showed the better result, but with the next two rails from Copenhagen tunnel, the circumstances being the same, the maximum of carbon gave the better result. Looking at the table, the only thing that seemed evident was, that the rail with the smallest amount of phosphorus was the best, and there seemed to be a pretty regular progression. He believed some engineers had lately inserted in their specifications the chemical test for steel and iron rails. With regard to the question of punch-

ing he felt compelled to differ from Mr. May. His own experience was that the effect of punching a steel rail was to weaken it. The material was brittle, and if in punching any little fractures were produced, however minute, even if hardly discoverable by the microscope, they were liable to increase; and with the jar and concussion to which rails were subjected mischief might be done. But drilling he had found to be a very serious matter. In the case of a large order for rails from the Barrow Company, drilling oval holes had been insisted upon; and the Company put up several machines made by Messrs. Sharp, Stewart, and Co., for the purpose; but all sorts of practical difficulties arose. The machines were so arranged that two rails were brought together and two holes in each rail were drilled at the same time, and it sometimes took eighteen minutes to get through the four holes. The order being for 6,000 tons, they were alarmed at the idea of spending so much time over the operation of drilling. It was also found that the skin of the rail differed so greatly, that where one tool would enter freely the next would be turned, and the tools would not travel at the same pace. All those difficulties were, however, surmounted by adopting the plan which Mr. Williams had described, viz., punching a small hole first, through which a cutting tool could be put, taking a centre on the other side, and then cutting an oval hole, or rather an elongated hole with two round ends. The rule adopted was that every hole should have at least $\frac{1}{8}$ inch cut away by the cutting tool. Again, with regard to cogging and hammering, he could not help thinking that sufficient information had not been obtained. The Author had supplemented the Paper by additional remarks on this subject, but in the Paper itself there was not enough to justify the conclusion, that the one plan was better than the other. Engineers in charge of the maintenance of way state that they had no occasion to complain of the fish-plates, and that they saw no reason for incurring the expense of deeper ones. It appeared that the fish-plate in Fig. 22 broke the rail. It was manifest that there was more iron in it than was needed. The joint was said to be 66 per cent. of the strength of the solid rail. By adopting the customary plan of reducing the bearings to 2 feet at the joint instead of 3 feet elsewhere, there would be a gain to nearly the extent of the loss thus indicated, and the joint would be as strong as the rest of the rail. The result seemed to point to there being too much material in the fish-plate. Looking at the section adopted on the Metropolitan railway, it appeared that neither the fish-plate nor the rail gave way, but the bolt. That seemed to betray a bad-fitting

fish-plate. He did not think that the ultimate strength of the joint was that which it was needful to ascertain, but the stiffness ; so that one rail should not deflect before the other. His opinion had always been, that a fish-plate should be so made that no sheer could come on the bolts, but that their work should be limited to holding the two cheeks together. In the case in point it appeared that the bolt was doing work that ought not to be required of it. If the shoulder of the plate had been made to fit under the rail, either the rail or the plate must have gone before the bolt, or the thread must have stripped. He hoped to hear whether the plate in common use, when well made and fitted, was found in practice to be unequal to its work.

Mr. LANGLEY said, in 1874 he laid down some permanent way near Stepney on the Blackwall branch of the Great Eastern railway, where there were upwards of three hundred trains a day passing over a single line. The weight of each train was, on an average, about 150 tons, making a total of about 45,000 tons daily over one line of rails. The permanent way on this length was composed of both steel and iron rails (from nearly all the principal manufacturers in England), weighing 80 lbs. to the yard, and keyed in cast-iron chairs resting on rectangular sleepers. The steel and iron were purposely laid close together so as to be under precisely similar conditions of wear and tear. The greater number of the wrought-iron rails had to be turned in one year and three-quarters, during which period they had worn down about $\frac{1}{8}$ inch ; but they had not to be turned on account of this wear, but because they gave way in places either by bulging or by splitting. The steel rails had worn about $\frac{1}{16}$ inch in one year and three-quarters, after about 27 million tons had passed over them ; which was rather in excess of the figures given by Mr. Williams. The fact of the wrought-iron rails wearing away twice as much as the steel was not an indication of the true value of the two metals ; because the steel rails after wearing down $\frac{1}{16}$ inch were still available, and would continue to be so until nearly the whole of the head was worn off, the wearing down being regular and uniform. The iron rails, on the other hand, were crushed in places and no longer fit to remain in the road. He had found that the old rails were far more durable than the new ones now supplied by manufacturers. The latter were like a bundle of fagots not tied properly together, and always gave way either by bulging or by splitting ; in fact, their life was most uncertain, while the old rails wore down more like steel rails. He had invariably put the sleepers about 2 feet apart at the joints, increasing the distance to about 3 feet in the centre

of the rail. This being done, and with the ordinary fish-plate properly screwed up, the joints could not be felt, and a continuous elastic line of rails was obtained.

In February 1873, at the Nine Elms goods-yard on the London and South-Western railway, he had laid a steel rail on one side and an iron rail on the other side of the shunting road where there was most traffic, an average of nearly four hundred engines and trains passing over this line in the twenty-four hours. The steel rail at the present time was in good condition, a layer of $\frac{3}{16}$ inch being worn off; while during the same period, over three years, on the opposite side the iron rail had been renewed three times, the renewal taking place after each rail had been turned, and both heads so worn that the rail was unfit to remain.

It was curious to notice the difference of opinion amongst Engineers as to the best form of rail section. On the Continent and in America, Engineers had almost invariably used the flat-footed rail; and he noticed last week that, on some of the western lines in France, rails keyed in chairs were being replaced by flat-footed rails. On the Metropolitan line, on the contrary, the flat-footed rail was being taken up and the rail in chairs substituted. The only recommendation the flat-footed rail had appeared to be its smaller cost in the first instance. It was more difficult to maintain and did not make so elastic a road. The cost per ton for rolling a flat-footed rail was more than that of a double or bull-headed rail, and the chair rail was taken out and replaced much quicker than a flat-footed one.

He had always found that, with heavy traffic, the second head of a wrought-iron double-headed rail, when turned, had lasted as long as the first. This was the case with all the rails laid down at Stepney. There was, however, no advantage in making a double-headed steel rail. Almost all of the relaying of the Great Eastern railway was being done with steel bull-headed rails.

Mr. COWPER observed that the question of the amount of carbon in steel had been thoroughly investigated, and a great amount of evidence on the subject would be found in the Transactions of the Iron and Steel Institute. He wished to draw attention to the fact, that inasmuch as there had been thousands of tons of steel rails made in early times by the Bessemer process, without sufficient manganese to give the best results, it was necessary to be very careful in comparing the results of the wear of steel rails having different proportions of carbon in them; it was especially so when the rails contained other impurities, such as sulphur, phosphorus, silicon, &c., as manganese was a great corrective of

their evil influences, and good ingots, that would bear hammering, cogging, and rolling, could be made when sufficient manganese was used, in cases where they could not be without. He had seen bad crop ends, 3 feet long, when sufficient manganese was not used, and again the circumstances totally changed and good ends made with a more liberal use of manganese. It was not, however, altogether a question of the amount of manganese in the finished steel, and he believed that in the Bessemer process some of the manganese used was not found in the finished steel, but did excellent service in the converter, by uniting with the silica and forming a slag with it, thus purging the steel of silica, whilst some portion of the manganese also effected good by absorbing the oxygen from "overblown" particles of iron, which would otherwise have set up ebullition by forming carbonic oxide with a portion of the carbon, and thus causing honeycomb. Another point that could not be too carefully guarded against was, that of comparing rails that had not been treated in precisely the same manner; thus one might be thoroughly annealed, and even kept warm for a time in the midst of a large heap of red-hot rails, and another, precisely like it, might be chilled to such an extent as to be rendered considerably harder. It was, however, a fact that good steel, with 0·1 or 0·2 per cent. of carbon, might be heated and quenched with impunity; but with 0·3 per cent. of carbon the steel might harden or not, he believed, according to whether it contained other substances or not. Manganese was important in steel having a low amount of carbon, as well as to give toughness to steel having a higher percentage of carbon together with impurities. There was now no difficulty in making a regular uniform quality of steel plate with a very low portion of carbon in it, and thousands of such plates, having greater ductility than iron, had been made without a failure. He exhibited a piece of rail of a section designed by the late Mr. John Braithwaite for the Colchester branch of the old Eastern Counties line, which was laid in 1843 and taken up in 1868. It was a Low Moor rail, and showed no spreading or lamination; a layer of $\frac{5}{16}$ inch had worn fairly away, and the rail was of as good a shape as ever. The section was adapted for giving a suitable support to the wearing surface.

Mr. RILEY said, as he had analysed rails for Mr. Price Williams, and had not only examined them chemically, but, as far as he could, mechanically, he might be permitted to make a few remarks on the condition of the rail and on the carbon question. Engineers might be somewhat perplexed by the statement that the results

given confirmed the remark made by Mr. J. T. Smith, M. Inst. C.E., that greater hardness of material did not conduce to the longevity of steel rails. He did not quite agree with Mr. Price Williams on that subject. The question was, did the percentage of carbon necessarily indicate hardness of rail? He thought not. Mr. Menelaus, M. Inst. C.E., than whom, perhaps, there was no better authority in the country, had said not long since that it was due to the engineers that the steel rails now made did not stand as they formerly did. He attributed it to the falling-weight test that engineers insisted upon, which required the manufacturer to put less carbon into the rail, and so to make a softer and tougher material. It was perplexing to find two eminent authorities disagreeing on such a point; and the question was how the two statements could be reconciled. Did it necessarily follow that because a rail contained a certain amount of carbon it had a certain amount of hardness? He believed not. The rails from the Great Northern line had been sent to him with the remarks of the engineer, and they were carefully analysed by himself, his experiments being verified by the colour test applied independently by another person. It would be seen from the figures that the percentage of carbon did not necessarily indicate the hardness of the rail. Taking the rails shown in Table 7 it would be seen that the analyses were exactly the same; for although it might be said that there was a difference of 0·02 per cent. in carbon, he could say, as a practical chemist, that it was impossible to come nearer than about 0·02 per cent. One of these rails was hard and the other soft. They were quite different mechanically; but chemically they were the same. He was inclined to think that it was not so much the percentage of carbon as the way in which the rails had been cooled that should be taken into consideration; 0·40 per cent. of carbon would give a very hard rail. He had had pieces of rail sent to him containing that amount of carbon, and they could only with difficulty be touched with a tool; and, on the other hand, he had had a steel bolt containing 0·8 per cent. of carbon which he could drill easily. If a rail were made with from 0·2 to 0·3 per cent. of carbon, and cooled when red-hot in water, a tough and moderately hard material would be obtained. The rails that had been referred to as having been put into cold water and punched contained rather under 0·2 per cent. of carbon. Mr. Smith's test in reference to punching rails appeared to him to be a most valuable one. If the rails were hardened as he suggested, and contained 0·35 or 0·4 per cent. of carbon, he believed the material would break the tool

applied to it; but he intended to make some experiments on that subject. One of the most interesting points in the analyses was, that in some of the rails there was a considerable amount of phosphorus, in one case nearly 0·25 per cent., and in some cases 0·2 per cent. If it could be shown that fair steel rails could be made with that amount of phosphorus it would be of great practical use. His impression was that the amount of phosphorus at present set down for rails was rather too low. He admitted the tendency of manganese to harden the rail, but he could not quite agree with the conclusions to which Mr. Cowper had arrived. There was one rail on the Metropolitan line having 0·64 per cent. of silicon, and the result of the analysis led him to regard it as a most dangerous rail. With reference to colour tests he might mention that some of Siemens's metal was said to contain 0·2 per cent. of carbon according to the colour test; but, on carefully examining it, he found it only contained 0·05 per cent. In experimenting with the colour test he had found it impossible to determine the quantity of carbon in the very low steels. He had no desire, however, to throw any disparagement upon the colour test, which he thought a valuable and practical one. His own experiments had been tested in that way, and the results were marvellously near. At the same time he found that errors were occasionally made, because two persons did not always see the same colour, or see the same thing in the same way, or they might have a different standard.

Mr. TOMLINSON wished to correct the statement in the Paper that Plate 17 indicated the "renewals of permanent way on the Metropolitan railway since the opening of the line." It only gave the result of the three years from January 1873 to December 1875. Many parts of the line approaching the stations had previously been relaid by his predecessor. Plates 12, 13, and 14 exhibited such varying results that he must suppose the circumstances were different, and therefore the figures could only be useful to those who knew the exact conditions of the lines. The table exhibiting the life of steel rails at forty-two years astonished him, as on no main line of railway could such a life be expected, judging from his own experience. On portions of the Metropolitan railway where no breaks were used, experience indicated a life of only about eight years, or a total of 100,000,000 tons passing over a pair of rails. The line had been originally laid with iron rails, which, so far as he could ascertain, had an uncertain life of from a few weeks to about one year. Portions of the line had also been laid in its earlier days with Dodd's case-hardened rails,

and these too had given way speedily. Then small steel rails, weighing about 65 lbs. per yard, $3\frac{1}{2}$ inches high, of the Vignoles section, had been laid here and there, some few of which were still in the branch-roads. In 1866 and 1867 the whole line had been laid with steel rails, weighing 84 lbs. per yard, of the Vignoles section, $4\frac{1}{2}$ inches high, with a base of 6 inches, and this form was still in the road from King's Cross to Bishop's Road. In 1866 the line was opened from Farringdon Street to Moorgate Street, and laid with rails of the same section, but they had all now disappeared.

In arriving at the fair life of a rail, circumstances should be taken into account besides the rail; and in his opinion the sleepers and ballast had a great deal to do with the results. In the diagrams showing the wear of the Metropolitan rails (Plate 18) great difference of wear was shown, although the trains were practically the same. The rails Nos. 1 and 2 were laid on sleepers 10 inches by 5 inches, notched for the cant of the rail, and therefore only $4\frac{1}{2}$ inches thick; whereas the rails Nos. 3 and 4 were carried on sleepers 12 inches by 6 inches, and baulks of 13 inches by $6\frac{1}{2}$ inches. Rail No. 5, on a line worked as a single line, had been laid on sleepers 10 inches by 5 inches, cut like Nos. 1 and 2. Rails Nos. 6 and 6a were on baulks 13 inches by $6\frac{1}{2}$ inches; and he thought the difference in the wear would prove the advantage of a good substructure. Rail No. 6a was in a place subject to dropping water, and this was probably the reason for its excessive wear compared with that of its neighbour. The small scantling of the sleepers was, he thought, the cause of the short life of the rails, and accounted for the rails laid in 1866 between Farringdon Street and Moorgate Street having all disappeared. They were laid on sleepers 10 inches by 5 inches. This road gave so much trouble to keep up, that he began to relay it with the large bull-headed section of rail, weighing 86 lbs. to the yard, at the newest end of the road.

In estimating the fair wear of rails, the character of the work should be considered quite as much as the number of tons passing over the line. Speed was an element of great importance. Rail No. 6 had suffered more than rails Nos. 3 and 4, although supported on the same class of sleepers, as the trains ran at fully 30 per cent. higher speed in the former instance.

He was surprised at the wide differences in the quantity of carbon contained in the rails referred to in the diagrams, and he was still more puzzled at the results; as in some cases excess of carbon seemed advantageous, and in other cases the reverse.

He had come to the conclusion, from many examinations, that the fair average life of a steel rail was represented by a wear of $\frac{1}{16}$ inch for each 5,000,000 tons passed over it. The table for the Metropolitan railway gave nearly this. The Great Northern, Table 6, eliminating No. 24 rail (which had most likely been changed), showed a life of 4,376,571 tons for each $\frac{1}{16}$ inch wear of the table. Nearly the same result was obtained with the Crewe rail, C, Table 5, although perhaps it could hardly be taken as a guide, as all the rails drawn had been worn out, so far as the main line was concerned, long before they were taken up, owing to the want of more rigid fishing.

Railway engineers had to think not only of the wear, but of the safety of a rail. He had known rails break in two on being dropped from a truck to the ground; and it certainly would not be safe to put such rails on any main line. Fishing the joints carefully was highly conducive to the longevity of the rails, and this, he thought, had not been hitherto sufficiently considered, nor the most suitable form of rail for fishing. He had tried to design rails for the renewals, so that the fish-plates should rest on angles instead of curves. The fish-plates were of a deep form which came below the rails: they weighed 48 lbs. a pair, and were 20 inches long. When tested with 5-foot bearings by Mr. Kirkaldy they showed about 67 per cent. of the strength of the rail. He laid the sleepers 2 feet 8 inches apart from centre to centre, and put nine sleepers of 12 inches by 6 inches to a rail 24 feet long. The equal spacing enabled the long fish-plate to be inserted. The original road had been laid with fishes 16 inches long, but as the depth between the head and flange was small the joints soon gave way, and the rails showed signs of wear towards the end, or where the wheels left one rail and reached the next. This, in a few months, extended over a length of about 1 foot, the ends of the rails being worn down nearly $\frac{1}{8}$ inch. Recently he had a large number of broken and cracked rails, resulting from their having been punched, which had all given way along the fish-holes, showing an incipient fracture, that had extended. He did not think that punching a small hole and subsequent drilling would be so trustworthy as complete drilling; it was impossible to punch a hole of less diameter than the thickness of the web of the rail, and if the web was $\frac{3}{4}$ inch thick the hole punched must be $\frac{3}{4}$ inch in diameter, so that enough metal would not be left for the removal by drilling of the portion damaged by the punch.

Mr. BRAMWELL mentioned an old project of his for doing away

with crop ends, and with the risk of having bad ends to the rails, arising from a desire to minimise cropping as much as possible. It had been stated by Mr. May how, when cogging was done by rolls instead of by hammering, there was a concave end to the bloom, and that when the rail was finished this concavity became rolled out into an imperceptible crack, which, if a large crop end were not cut off, was left in the rail and injured it, manifesting itself in work. Mr. Bramwell's proposal, which he hoped some day to see carried into effect, was to manufacture rails as weldless and endless tires were manufactured; that was to say, by rolling each rail in a hoop form, then cutting it open, and rolling it out straight. In such a mode of manufacture there would be no crop end and no unsound part, because a hoop, having neither beginning nor end, would be uniform in quality throughout.

Dr. SIEMENS said there seemed to be a great divergence of opinion with regard to the quality of steel composed of different percentages of carbon. Mr. Riley, who had given considerable attention to these questions, no doubt could have supplemented the information by further chemical details, which perhaps he did not like to do because there was at present doubts as to the specific effect produced by other materials, such as phosphorus, sulphur, silicon, &c. Dr. Siemens might perhaps be able to supply some data regarding steels in which the proportions of different materials reached their limits on the one side or on the other. It had been said that steel containing a considerable percentage of carbon, 0·4 per cent., was very soft. That might be partly owing to the tempering, for if the steel had been slowly cooled it would be soft, but it might also be owing to the manner in which the carbon was combined. Carbon was not always chemically combined even in steel. In the process of mixing spiegeleisen with the blown metal at the last moment in the Bessemer process there was hardly time to form a chemical combination, and hence metal might be produced which contained a considerable proportion of carbon, and yet was essentially soft metal because the carbon was not chemically combined. He had observed, in boring a large cylinder of steel cast from metal of that description, that at one point the boring tool went deeply into the metal, and at another point there was a resistance as though the metal were hard. In such a case no effect of temperature, of sudden cooling, was involved, because of the particular form of the metal. The phenomena showed clearly that steel was not always homogeneous unless special care had been used to make the mixture

perfect. Mr. Cowper had attributed to manganese the quality of making the metal tough, whereas carbon made it hard. That was not universally the case. In the case of steel containing as much as 0·4 or 0·5 per cent. of carbon, little manganese was desirable or necessary to make the metal forge properly; but in the case of very soft metal, and metal containing phosphorus, the manganese was an essential condition. For instance, 0·2 per cent. of phosphorus, which was about the maximum amount admissible, necessitated about 0·4 per cent. of manganese to make the metal at all workable and to prevent its extreme brittleness when hard; but in metal containing hardly any carbon, less than 0·1 per cent., manganese was of the utmost importance, and without it the metal could not be got to work or stand against the grinding axle. The manganese seemed to bind the particles of metal together, and to make it more homogeneous. Mr. Riley had mentioned the difficulty of determining such a slight amount of carbon by the ordinary colour test. No doubt the difficulty was great, but Mr. Willis, of the Landore Works, had introduced a test for determining a very slight proportion of carbon, sufficiently accurate for all practical purposes, by dissolving the metal in nitric acid and observing the effect of colour on the solution. The nitric acid did not act upon the carbon, and it produced a brown tinge of sufficient intensity to be distinctly observable, even though the proportion of carbon should be considerably below 0·1 per cent. This test would enable manufacturers to produce steel of extreme mildness, such as was now used largely for engineering purposes. It was impossible to estimate so slight a difference in carbon as 0·05 or 0·1 per cent. by any mechanical test; but by a ready chemical test of that kind the manufacturer was enabled to bring the metal down to an exact point considerably below 0·1 per cent. No doubt these questions were at present only partially understood, and much work was still required in order to arrive at certain conclusions regarding the conditions necessary to produce steels of definite qualities. If steel was produced from pure iron, such as was found in Sweden, a metal could be made containing hardly any manganese, and only a trace of carbon, and no appreciable percentage of phosphorus or silicon; and metal of that description, which was as nearly as possible of pure iron, was perhaps the toughest that could be made, exceeding in toughness copper or even silver. A further advantage of such metal was that it was less liable to rust. Experiments lately made in France showed a percentage of rust, as compared with wrought and cast iron, in the proportion of 0·4 to 1·4, being much in favour of a pure metal such as a very

mild steel—a quality of great value for shipbuilding and purposes of that kind.

Mr. BRUNLEES had on a former occasion expressed the opinion that the fish-joints of railways were the most unmechanical things connected with them, and he had no hesitation in repeating the statement. He thought there was room for improvement in fish-joints, and he was glad to find that the attention of Mr. Tomlinson was directed to the subject. He considered the best rail was that which had plenty of metal in the head and a small proportion in the foot, forming what he would call a girder section. In that case the metal was properly distributed, and both the tension and the wearing part were where they ought to be. If such a rail was more generally adopted, better results would be obtained. He knew of no form of permanent way better or stronger than that of smaller dimensions, which he had used in 1852 and ever since, both at home and abroad, with excellent results.

Mr. RILEY said it was certainly an omission on his part not to have mentioned the different conditions in which the carbon existed in steel rails; but, having so many analyses to make, he had not been able to complete the tests, but he intended to do so.

Mr. SANDBERG observed, through the Secretary, that few, if any, foreign governments or departments of public works could show information of equal value to the statistics collected by the Author, and illustrated in this and other Papers on the railways of Great Britain. The Paper entered into the metallurgy of iron and steel as applied to railway bars, a subject which he had made his speciality, and he would therefore offer some remarks, based upon his practice as inspector of rails for seventeen years for the Swedish government and other railways. The Paper furnished ample proof of the superiority of steel to iron for railways, unless the traffic was very light. The price of steel rails had been reduced during the last ten years from double that of iron to only 25 per cent. more than the price of iron, but he feared at the expense of their quality. Since it had been attempted to produce steel rails of inferior and cheaper raw material, engineers should be on the lookout for their safety more than for their durability, as they and not the makers were answerable for the consequences. Owing to the great competition now existing in a slack state of trade, the tendency was to cheapen the make and to “avoid loss” by manufacturing rails regardless of their safety, which in his opinion was of greater importance than durability. With this view he would

warn railway authorities, particularly those who, like his friends, had to contend against a cold climate, not to sacrifice the safety, tenacity, stretch, or extensibility of the steel for greater durability through hardness; all the more so if this hardness was produced by phosphorus or silicon, which also made it brittle, instead of by carbon and manganese. It had been stated that an amount of 0·2 per cent. of phosphorus was the maximum admissible, but only half that could be safely tolerated for a cold climate, admitting, however, that the smaller the amount of carbon the greater could be the amount of phosphorus in the steel without brittleness. Hard steel could be rolled better than soft. There was some difficulty in determining the amount of carbon in steel by the Eggertz coloration test when the amount was small, but Professor Eggertz had lately told him that sufficient accuracy for all practical purposes could be obtained if the solution was made at a temperature of 176° Fahr., and also if no light was admitted during the process, for which purpose a special apparatus had been constructed.¹ He had supplied standard steel, obtained direct from Professor Eggertz, to many steel-makers, in order to facilitate the testing of every cast, but he was sorry to find that there were still many steel-works without either a laboratory or a chemist, which he thought highly necessary in these experimental times. In his opinion the cogging was a more severe test for the steel, as generally it gave more wasters than the hammer, which latter would only work steel somewhat red-short into clean rails. He thought that drilling was safer than punching rails; still, if the steel was soft and the hole not too near the end, so as to leave, say, a depth of 1½ inch of solid metal in the web of the rail, punching was safe enough. Another means to obviate the breakage of iron or steel rails in the punch-holes was to prevent the blow against the bolt on the upper part of the hole every time the train passed over the joint by making it as stiff as the solid rail; the ordinary weak joint was no doubt the cause of that mischief. He had tried many experiments both by dead weight and blow on the strength of rail joints,² and could confirm Mr. Brunlees' opinion as to the inferiority of the ordinary rail joint. For existing lines, with the joint sleepers as close as practicable, angle fish-plates having 67 per cent. of the stiffness of the solid rail would probably be the best. Such were now laid on the Swedish State railways without base-plates, extending vertically to the flange of the rail and horizontally to

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. xliii., p. 411.

² *Vide* "Engineering," 25 November, 1875.

allow four holes for spikes to be punched through the flange so as to nail them both inside and outside to the sleeper; thus the road would be better kept both horizontally and vertically than by the ordinary fish-joint. For lines in construction the best joint, in his opinion, would be a fish-plate of such depth as to afford the same stiffness and elasticity to the rail joint as the solid rail with the same distance of joints as of sleepers, say 3 feet from centre to centre. With such a fish-joint applied to a rail-section of small fishing angles, say from 11° to 15° , so as to throw less work upon the bolt than with the pear-formed rail-section of 30° , neither breaking of bolt-holes in the rail, nor sinking of the joint, with too early failure of the rail ends and rolling-stock, would be risked, and this would, in his opinion, materially reduce the maintenance and renewals, and increase the money life of the permanent way.

Mr. R. H. TWEDDELL remarked, through the Secretary, that a large portion of the cost of maintenance and renewals of the permanent way of railways had been shown to be due to the fact that the crossings, as now made, formed their weakest part. He believed that the continuous crossing, designed by the Author some years ago, in order to remedy this defect, effectually preserved what might be termed the 'continuity of elasticity' of the line, obviating the objectionable anvil-like action of cast-steel crossings, and the looseness and want of continuity of the ordinary forms; but the cost of manufacture had hitherto prevented its being offered at a price sufficiently low to insure its general adoption. Again, in the previous form of these continuous crossings, a special or solid section of rail had to be used, to insure sufficient material in the web after the groove was slotted out, and involving special machining at each end to enable the connection to be made to the next rail by the usual fish-plate. Hence it occurred to Mr. Price Williams that hydraulic pressure might be adopted to make these crossings, and Mr. Tweddell had designed a machine for this purpose, and had successfully applied it to some Landore Siemens' steel rails of the 80 lbs. double-headed section, which were passed through a special set of dies and stamped into the finished form. The question was simply one of forming the dies so that portions of the rail were forced to flow while hot into spaces prepared for them: thus the material was moved from where it was not required, and utilised by being placed where it was specially wanted to strengthen the rail, so that the crossing became uniform and equally elastic with the rest of the permanent way. A saving of 50 per cent. was effected in the first place in the material of the crossing, inasmuch as the weight of solid rail, as

compared with the ordinary rail, now required was as 120 to 80; and finally all machine-work was dispensed with, as the squeezing was done at one blow. In Mr. Tweddell's opinion, it was difficult to place any limit to this illustration of the practical application of M. Tresca's researches on the flow of solids; and he believed by this process wrought-iron or steel railway chairs might be made almost as cheap as cast-iron ones. Should this prove to be the case, further economy would be effected in the maintenance of permanent way.