No. 1,429.—“On Bessemer Steel Rails.”¹ By JOSIAH TIMMIS SMITH,
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THE manufacture of steel has of late years so greatly increased, and the scientific discoveries in connection with it have been of such vast importance, that, whilst at a comparatively recent date, a short treatise might have included most of the salient features in reference to the science and manufacture of the metal, at the present time only one section of the subject can be conveniently considered within the limits of a paper.

Of the different kinds of steel, it is proposed to refer only to that made by the Bessemer process; for though the Siemens and Siemens-Martin processes may be equally available, yet the Author has had no experience with those processes, and the many experiments he has instituted, extending over several years, have been exclusively made on Bessemer steel.

Probably there has never been an industry of such magnitude as the Bessemer steel manufacture with so short a history. Less than twenty years have passed since Mr. Bessemer first announced his discovery. Unlike most industries, where each step has been but a slight advance on its predecessor, the manufacture of Bessemer steel, especially within the last six or seven years, has made giant strides; and in some important uses it threatens to supplant iron where, until recently, that was believed to be the only available metal. This is doubtless due in a great measure to Mr. Bessemer's persevering industry. Long he laboured in obscurity to perfect the metal, in which none but himself had confidence; and, when the results of the last ten or fifteen years are considered, it is impossible to conjecture what another decade may produce. Under these circumstances it need not be a matter of surprise if Bessemer steel-makers have to acknowledge that much of what daily occurs in their works is not thoroughly understood, and that there is still much to learn in the metallurgical and mechanical operations, before the system is absolutely perfect.

Rapid as has been the increase in consumption, there is little doubt that the ratio would have been still higher, if engineers had

¹ The discussion upon this Paper was taken in conjunction with the preceding one, and occupied portions of three evenings.

greater faith in the constancy of the qualities of this metal, of which without trial it is impossible to judge with certainty by external appearance alone. Though it is universally acknowledged that Bessemer steel is capable of possessing most valuable qualities, yet many engineers still have doubts as to their constancy, and hesitate to use, at a much lower cost, a material possessing greater ductility, and capable of enduring 50 per cent. more tensile strain, than the highest brands of iron, with probably a greater power of resisting oxidation.

The object of this Paper is to endeavour briefly to show that, with care in manipulation and in selection of materials, Bessemer steel may be produced constant in quality, and that certain inexpensive tests may be applied which shall absolutely determine the quality of the material, in most if not all of its characters, so far as is required for railway purposes.

After an extensive experience in the manufacture of Bessemer steel rails, the Author can only come to the conclusion that the present system of inspection is highly unsatisfactory, and that whilst it sacrifices a great number of rails, it gives anything but reliable results. The object appears to be to test each individual rail in such a manner that its value shall not be deteriorated. With this view many experiments have been made; and it is hoped that a system has been developed which although primarily adapted for rails, may be made available for any other form of steel. The experiments appear to prove, that, if it be possible to determine the hardness of the material, all the other properties may be calculated therefrom. If, therefore, the fish-plate holes in the rails be punched by a registering punching press, an index is obtained for the real quality of the steel. It is not proposed to give the details of this press; but it may be stated that nearly all existing presses, at a small cost, may be made to register the force exerted to punch the fish-plate hole. Experiments have shown that this force increases, according to the thickness of the metal, in strictly arithmetical progression; for a hole $\frac{7}{8}$ -inch in diameter the force required is about 8 tons per $\frac{1}{8}$ inch.

Experiments have demonstrated that the zone of metal injured, by punching steel having a tensile strength of not over 32 tons, is not more than $\frac{3}{32}$ inch in breadth, and that if the fish-plate holes are first made with a small punch and then enlarged by drilling to the required size, the steel is not more injured than if the hole had been drilled only. The Barrow Steel Company have shipped to Canada more than 100,000 tons of rails treated in this manner; and as there has been no case, to their knowledge, where rails

have broken through the fish-plate holes, they consider it a most satisfactory proof that no danger need be feared. On the contrary, this mode of punching is one of the best practical tests of the quality of the steel; as, however hard (unless in an exceptional degree) it may be, the particular rails, if drilled, may be overlooked by the management; whilst if the steel has a greater tensile strength than 34 tons to 35 tons, the punch will break, when the rail would necessarily be rejected. During the past few years numerous experiments have been made on rails where there had been a fracture through the fish-plate holes, and in no instance had the steel a less tensile strength than 35 tons.

To proceed to the main portion of the subject. The experience at Barrow, where Bessemer steel rails have been made for nine years, shows that, with ordinary care in the selection of materials and in manipulation, there is no difficulty in producing mild steel of constant quality, though occasionally, from accidents in the earlier stages of the process, small quantities will be made of exceptional character, and such material, if not at once detected, would inevitably be discovered by the registering punching press. It has further been found that, for rails, pre-eminently the best material is steel with 0·3 per cent. of carbon and a tensile strength of 32 tons, or not varying more than from 31 tons to 33 tons. Such rails are absolutely certain to withstand any shock that can be applied in punching or ordinary wear, and they will never fracture under the most severe 'tup' test at the first blow. Numerous experiments have proved that, if the tensile strength does not vary beyond the given limits, the remaining qualities can be predicted with exactness; but when the tensile strain exceeds 34 tons, no such absolute dependence can be placed on the steel. For some time it has been known that the ductility of Bessemer steel bears a certain ratio to the tensile strength, and when the strain is of a medium character, the ratio of the ductility is nearly constant, the one diminishing as the other increases. When the tensile strength increases beyond the standard point, the results begin to be uncertain and variable. This deterioration in the quality may be due to a variety of causes, such as inferior materials, too rapid cooling, or fault in manipulation; and it is possible, by a combination of circumstances, to obtain Bessemer steel of so high a tensile resistance, and of such extreme hardness, as to defy the power of a tool made of the best cast steel. But though such a material would have great value under certain conditions, and, in the form of rails, would stand almost indefinite wear if trains passed over at invariably slow speeds, there would

be the minimum of elasticity, and no reliance could be placed upon them. Such steel may be dismissed from further consideration, as being unsuitable for general railway and structural purposes.

Recently a new series of experiments was instituted at the Barrow works, with a Kirkaldy press, on rails weighing 73 lbs. to the yard, such as are supplied for the Furness railway. The specimens were taken from the middle of the web, a large number of rails being selected for experiment; they were analysed for the carbon percentage, tested for their tensile strain and elongation, and in corresponding specimens $\frac{3}{8}$ -inch holes were punched, and the force required to do so carefully registered. The results proved that the punching strain was a true index of the steel as to its carbon percentage, tensile resistance, ductility, and the force required to give a permanent set. It was felt that all that was then wanted to render the experiments worthy of being brought before the Institution, was to know the actual wear of rails of different degrees of hardness. There appeared to be no means of obtaining this, when, fortunately, it was found that the Furness Railway Company had just taken up a length of 2 miles of steel rails, laid down in 1866, on their Ulverston incline of 1 in 80, and which were amongst the first made at the Barrow works. It was then determined to select from these, for another series of experiments, twenty hard and twenty soft rails. This plan had to be modified, as the rails, after being used six years on one side and two years on the other, were taken up, not on account of being worn out, but to be replaced by rails of another section, and were in process of being relaid on a different part of the line, and, although there were still a large number from which to select, only ten hard ones could be found. This may be taken as an indirect proof of the value of those made at that early period of manufacture. The results of the new series as to wear, as shown on the accompanying table (page 74), were altogether unexpected. Contrary to what might have been anticipated, greater hardness had not conduced to the longevity of the rails, and the softer ones showed the minimum of wear. It may also be noticed that where there is an excess of carbon the better qualities of the steel are lessened. So far as steel rails are concerned these experiments are highly satisfactory, as they show that eight years of exceptionally heavy traffic had not deteriorated the quality of the metal, except that the force required to break the rail was considerably reduced, making allowance for difference in weight. In order to account for this particular weakness some additional experiments were made. Pieces of the same rails were heated to a dull red and

allowed to cool gradually, when the breaking strain was found equal to that of a new rail of the same section and properties. In another experiment, the wearing surface, both at the top and bottom of the rail, was planed off to the extent of $\frac{1}{8}$ inch, when it was found that the flexibility of the rails was restored. From these tests it may be assumed that the material forming the wearing surface of the rail enters into a condition of extreme molecular tension; and, although the portion affected is certainly not more than $\frac{1}{8}$ inch in thickness, and may not improbably be much less, yet it exerts a very considerable influence on the elasticity of the whole rail and its power of resisting a bending strain, when such is applied on the opposite side of the rail, forcing outwards the worn surface. As, however, it is almost impossible for rails ever to experience in practice such conditions, it may be considered that this molecular tension exercises no deleterious influence on the longevity of single-headed rails. With double-headed rails it may be otherwise, and, though no instances are known to the Author, yet it is not difficult to imagine circumstances where an additional amount of impact, on a turned and much-worn rail, might cause it to break, under conditions where a new rail would successfully resist a far higher strain.

Great care was taken in the preparation of the accompanying table (page 74), and confidence may be felt in the accuracy of the tests and analyses. It will be at once observed that there is not an exact relative correspondence in the value of every rail; but this will be accounted for by the fact that these rails varied in weight to the extent of fully 1 lb. per yard. Disturbing influences of this character may alter to a small extent the individual figures in the table, but, taking the two divisions, the deductions already drawn are broadly intimated.

To sum up the foregoing experiments on Bessemer steel rails, it may be stated generally that the most lengthened wear under the heaviest traffic does not appear in the slightest degree to deteriorate any portion of the rail, except the wearing surface to an inconsiderable depth. But this part of the rail, however hard and capable of resisting impact, doubtless loses almost the whole of its ductility, which is apparently due to the extreme molecular tension of the particles of the metal. If a worn double-headed rail be turned, though the new wearing table will be as strong as when first made, yet it may be considered certain that the total strength of the rail is materially lessened by the weak under table, by which much of the elasticity of the rail is destroyed; but, by planing off a thin section, this, as has been

RESULTS OF EXPERIMENTS on double-headed BESSEMER STEEL RAILS, manufactured at the Barrow works, in wear on the main line of the Furness railway for eight years.

No.	Strain required to punch hole $\frac{1}{4}$ -inch diameter through web $\frac{1}{4}$ inch thick.	Bending strain required to produce permanent set. Supports 36 inches apart.	Tensile tests. Specimens from web.		Carbon.	Original weight of rail per yard.	Weight of rail per yard after wear.	Wear of rail per yard.	Percentage of wear.
			Breaking strain per square inch original sectional area.	Elongation. Length extended = 2 inches.					
	tons.	tons.	tons.	per cent.	per cent.	lbs.	lbs.	lbs.	
1	46·25	19	30·91	37·5	0·28	73	63·41	9·59	13·13
2	46·33	19	30·08	36·5	0·28	„	63·93	9·07	12·42
3	46·97	19	31·03	36·0	0·28	„	63·95	9·05	12·39
4	47·18	19	31·56	35·0	0·28	„	64·84	8·16	11·17
5	48·21	20	31·53	36·0	0·29	„	61·52	11·48	15·72
6	48·27	20	32·85	34·5	0·30	„	63·26	9·74	13·34
7	48·50	20	33·37	32·0	0·30	„	61·14	11·86	16·24
8	48·86	20	33·07	32·0	0·29	„	63·11	9·89	13·55
9	48·89	20	31·88	36·0	0·31	„	63·02	9·98	13·67
10	49·00	20	32·33	37·0	0·29	„	62·30	10·70	14·66
11	49·00	20	33·37	34·0	0·31	„	65·07	7·93	10·86
12	49·07	20	32·09	37·0	0·30	„	62·34	10·66	14·60
13	49·41	20	31·97	33·5	0·32	„	65·46	7·54	10·33
14	49·50	20	32·75	32·0	0·31	„	64·02	8·98	12·30
15	49·68	21	33·18	32·5	0·29	„	61·66	11·34	15·53
16	50·00	21	33·59	36·0	0·30	„	61·61	11·39	15·60
17	50·11	21	33·08	35·0	0·30	„	61·37	11·63	15·93
18	50·27	21	32·67	35·0	0·30	„	62·67	10·33	14·15
19	51·05	21	33·65	32·0	0·32	„	63·60	9·40	12·87
20	52·50	21	33·49	32·0	0·32	„	64·00	9·00	12·33
21	56·79	23	37·01	26·0	0·36	„	58·01	14·99	20·53
22	58·16	23	37·42	26·0	0·40	„	59·95	13·05	17·87
23	58·44	23	37·93	23·0	0·40	„	63·51	9·49	13·00
24	61·24	24	41·41	26·0	0·39	„	60·45	12·55	17·19
25	61·34	24	39·10	22·0	0·43	„	64·24	8·76	12·00
26	64·42	24	42·82	25·0	0·44	„	63·66	9·34	12·79
27	65·19	26	44·00	16·5	0·45	„	63·36	9·64	13·20
28	65·31	25	39·23	24·0	0·44	„	60·84	12·16	16·66
29	74·50	28	45·79	3·0	0·50	„	62·68	10·32	14·14
30	82·47	31	50·42	3·0	0·57	„	62·44	10·56	14·47

Soft rails.
Average wear, 13·54 per cent.

Hard rails.
Average wear, 15·18 per cent.

demonstrated by experiment, can be entirely restored, allowing for a proportionate decrease in the weight of metal.

The foregoing remarks relate more especially to Bessemer steel rails; but whatever advantage this metal possesses for that particular use, the Author considers even greater benefits may arise if it be employed for structural purposes. He regrets that there has neither been time nor opportunity to make any other experiments. For tires, axles, and forgings in steel the demand is daily

increasing, showing that experience proves the greater value of steel over iron for such uses. But there is no reason why its application should be so limited. If the Board of Trade and the Admiralty were to take up the matter in earnest, and, instead of throwing obstacles in the way of advancement, gave the prestige of Government aid, a short period might elapse before steel would be in extended use for bridges, girders, ship-building, and other forms where iron cannot now be employed on account of the greater weight of metal that would be necessary to obtain a required strength. In point of economy alone numberless structures could be erected if steel were employed that cannot now be entertained; bridges could be built of greater spans, and vessels could be constructed of largely-increased carrying capacity. Doubtless, steel will be adapted in many forms unthought of now, when it is acknowledged that a material can be obtained at a low cost of far higher quality than iron, and weight for weight of infinitely greater strength. It may be expected, too, that advances will be made in the direction of Sir Joseph Whitworth's fluid-compressed steel, where all the advantages of Bessemer steel are still further increased. If such a metal were adopted generally by engineers, they would have a material ready to their hands by means of which they could revolutionise the present science of engineering.