SOUND STEEL IN RAIL MANUFACTURE.

A Comparison of the Results obtained by the Pennsylvania Railroad with Rails rolled from Sink-head and ordinary Ingots respectively.

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It is a matter of common knowledge that the top end of any ordinary steel ingot—that is to say, the end which is uppermost during the pouring of the steel—suffers generally from a defective character. As the metal cools down and solidifies from the exterior of the ingot inwards, bubbles of gas or air enclosed in the molten steel during the pouring are forced inwards and upwards until they collect in a central "pipe," which extends a certain distance downwards from the top of the ingot. Impurities not wholly withdrawn in the slag also tend to collect in the same manner near the top of the ingot, occasioning segregation (a local increase in the percentage of content) of carbon and other elements, principally carbon and phosphorus, which has the effect of increasing the brittleness of the steel so segregated. On this account it is essential that, during the rolling, a sufficient percentage of the rolled-out bloom shall be cut from the end representing the top end of the original ingot to ensure—as far as it is possible to do so—soundness in the remainder. This crop is, of course, waste steel, and it is the desire of the steelmaker to reduce it to the smallest limit reasonably practicable. At the same time the purchaser of the rails is vitally interested in the adequacy or otherwise of the cropping performed at the mill—a matter which it is next to impossible to cover in any specification or to safeguard even if specified—seeing that insufficient cropping is bound to result in defective rails. Such defects may not reveal themselves in the tests, nor prove visible during the surface inspection, but may give serious trouble subsequently in the matter of broken rails.

The Production of Sound Ingots.

In these circumstances it is, perhaps, surprising that more detailed attention has not been paid hitherto to the question of producing thoroughly sound ingots. In this country only two physical or mechanical processes have been devised expressly towards this end. There is the Talbot process of compressing the ingots laterally before the metal has set finally in the centre—with the object of forcing the central pipe upwards towards the top of the ingot—known as "liquid squeezing" of the ingots; this method, while successful in operation, cannot yet be said to have attained any great vogue. The other process is that patented by Sir Robert Hadfield, wherein, after the ingot has been poured, the top is kept hot by means of an air-blast playing on a layer of charcoal, held in a specially designed "sand-head" fitted on to the mould, for a period from 20 to 40 minutes, until the metal in the head has finally set. This "sink-head" process has the effect of feeding molten metal into and thus practically eliminating the central pipe in the ingot, so that virtually the whole of the metal under the sink-head itself is sound steel.

The effectiveness of the Hadfield sink-head process has recently received striking confirmation from a series of tests carried out by the Pennsylvania Railroad. Impressed by the claims made in a paper read by Sir Robert Hadfield and Mr. Burgess before the American Society of Mining Engineers in 1915, entitled "Sound Steel Ingots and Rails," the rail committee of the Pennsylvania Railroad decided to purchase 100 tons of Hadfield sink-head ingots from Hadfields Limited, of Sheffield, and to have them rolled into rails. The rolling was carried out by the Maryland Steel Company, of Sparrows Point, Md., U.S.A.; at the same time a number of ordinary ingots were rolled into rails for the same company in order that a detailed comparison might be made, more especially as to the actual percentage of each ingot that was finally available as serviceable rails. The whole matter has been gone into with extraordinary thoroughness and minute attention to detail, and the results of the investigation are embodied in Technologic Paper No. 178 of the American Bureau of Standards, entitled "Steel Rails from Sink-Head and Ordinary Rail Ingots," written by George K. Burgess, physicist to the Bureau, and published at the close of last year. Apart from the subject under review, the paper is particularly interesting in regard to the sidelights that it throws on modern American rolling practice. It is, of course, impossible to reproduce here in full the extensive tabular matter of the report, and textual comment, but the salient features of the comparison, and the conclusions arrived at, are worth noting.

The Hadfield ingots numbered 37 in all; they were made in a small Bessemer acid converter, and each ingot represents a separate heat. Deoxidisation was effected in the moulds with aluminium; the ingots were cast bottom upwards, *i.e.*, with the sink-head above the large end of each ingot. The Maryland comparison ingots numbered 15, and represented portions of three different heats from basic open-hearth furnaces, made on three different dates. For the purpose of making the comparison as complete as possible, each group of five comparison ingots received different treatment in casting. Ingots M1–M5 were of "rising" steel, and were chilled on top with iron caps but not deoxidised with aluminium; ingots M6–M10 were also of rising steel, but deoxidised with aluminium, and chilled on top in this case with water; ingots M11–M15 were made from quiet or "killed" steel deoxidised with aluminium but not chilled. The sink-head ingots weighed 5,300 lb. each, and the comparison ingots, 7,300 lb. Comparison was thus made between four different kinds of steel—different, that is to say, as regards the casting practice employed—and of two types of ingot form. Chemical composition and test properties of all the ingots were on the average very similar, except that the comparison ingots contained a mean percentage of 0·75 nickel and 0·28 chromium, both of which elements were absent in the sink-head ingots.

Uniform Chemical Composition of Sink-head Ingots.

Stress is laid in the report on the uniform chemical composition of the sink-head ingots. An analysis taken from the rails at a position just under one of the top corners of the head reveals an average carbon content of 0·648 per cent., with an average deviation from mean as low as 0·017 per cent. The average phosphorus content in the same position was 0·032 per cent., with an average deviation of 0·002, and sulphur 0·047, with a deviation averaging 0·004 per cent. Manganese, averaging 0·89 per cent., and silicon, were also very uniformly distributed. Carbon estimated from the same position in the rails from the comparison ingots averaged 0·645 per cent., but the average deviation from mean was 0·036 per cent. Manganese in the comparison rails averaged 0·70 per cent., and phosphorus the low figure of 0·019; in group M11–M15, however, the phosphorus was at an average level of 0·028 per cent., which closely compares with the figure of the sink-head ingots, and for this reason, as well as the method of casting adopted in the case of M11–M15 ingots, this sub-group is really the best for comparison with the sink-head ingots. Sulphur in the comparison ingots reached high figures, and varied considerably in each sub-group, from an average of 0·076 per cent. in M1–M5 to 0·101 in M6–M10, and as much as 0·118 in M11–M15. The nickel and chromium in the Maryland steel have already been mentioned.

We now pass to the rolling methods. The Hadfield ingots, having been shipped from England, suffered the unusual disadvantage of being reheated from the cold condition. It seems unfortunate that, in order to make the comparison exact, the same procedure was not adopted in the case of some at least of the comparison ingots, but, although the question was considered, it was decided not to interfere with the ordinary practice, and the comparison ingots were, therefore, rolled immediately after casting. The sink-head ingots, after a slight preliminary heating to 50° C., were charged into relatively cool soaking pits (600°–750° C.), where the heat was gradually turned on after half-an-hour had elapsed, and was continued for from 17 to 21 hours in all in the case of each ingot. Comparison ingots were charged into hot pits in the ordinary way. Average temperature at which the rolling was commenced was 1,150° C. in the case of the sink-head ingots, and 1,166° C. in that of the comparison ingots; the average temperatures taken on the foot of the rail as it emerged from the last pass through the rolls were 1,014° and 1,001° C. respectively. The latter temperatures were taken by an optical pyrometer on the outside oxidised surface of the rails, which is cooler than the interior metal by some 75°–100° C.; this would make the true finishing temperature nearer 1,100° than 1,000° C., and accounts for the apparently large fall between commencing and finishing temperatures.

The section into which the ingots were rolled was the 100 lb. per yard Pennsylvania Railroad standard rail, and the reduction from ingot to rail was effected by 13 passes through the blooming rolls, after which each ingot, now of 8 in. by 8½ in. section, was cut into two blooms; there then followed, with no intermediate re-heating, six passes through the roughing rolls, four through the intermediate rolls, and one finishing pass—total, 24 passes in all. The whole of the resultant material, both serviceable rails, rejected rails and discard in the mill, was weighed with great care, in order to arrive at an exact estimate as to the proportion of each ingot which was ultimately serviceable. The customary surface inspection of the finished rails for defects was made in the ordinary way by the inspectors of the Pennsylvania Railroad Company.

Rail Examination Results.

It is now of interest to look at the results obtained from the examination of the rails. The actual extent of piping and segregation was arrived at by cutting back the top rails from each ingot, in 5 ft. lengths, until there was no further piping visible, and the segregation was within the maximum limit of 12 per cent., which constituted one of the controlling factors in the test. This was described as the "discard to sound steel." Owing to uncertainty as to the actual location of the sink-head junction it was found that an arbitrary allowance would require to be made in cropping these ingots in the mill, as otherwise there would be the risk of having the rails from the top of the ingot rejected. Thus an 8 per cent. discard only was found to occasion surface defects in at least one-half the "A" rails, caused by the junction between sink-head and ingot, the sink-head alone requiring an average discard of 9·1 per cent. All trace of piping appeared to be eliminated with an average discard of 11 per cent., and the effect of carbon segregation in excess of the 12 per cent. allowance was but little in evidence at this limit of discard. It should be added that any steel showing more than 12 per cent. segregation of carbon, either positive or negative, was discarded as unfit for use.

In the final analysis an average of 4·3 per cent. was cropped in the mill from the top of the sink-head ingots, and 2·5 per cent. from the bottom, at the blooming mill. At the hot-saw the percentage loss on account of hot-saw crops from both ends of the bloom, and the special test pieces cut in all cases, amounted to 3 per cent. In the examination of the rails. 9·1 per cent. was discarded on account of the sink-head; in all, 11·5 per cent. of the sink-head steel was discarded for chemical and 7·2 per cent. for physical unsoundness. The steel finally available for rails amounted to 81·6 per cent., on the average, of each original ingot, and this result would have been improved were it not that the re-heating of these ingots from the cold condition necessarily involved loss of weight averaging some 2·9 per cent., owing to the additional length of time occupied in the soaking pits. This circumstance, coupled with the fact that the Hadfield ingots almost all suffered from external roughness in a more or less degree from the casting methods employed, is responsible for the fact that 41 per cent. only of the sound rails rolled from the sink-head ingots were classed as of "No. 1" quality, the remaining 59 per cent. being of "No. 2." quality. In this connection it should be explained that it is the custom to accept in all American specifications a certain proportion of second quality rails, containing small surface defects only, for use in locations of secondary importance. For the reasons given, however, the high proportion of second quality rails from the Hadfield ingots is not stressed in the report.

Comparison of Percentages Obtained on Final Analysis.

The comparison of these percentages with those obtained from the ordinary Maryland ingots is striking. The Maryland crops at the blooming mill and at the hot-saw were similar to those made in the case of the rails from the sink-head ingots. But in making the "discard to sound steel" the effect of piping and segregation in the ingots is clearly apparent, as also the influence on the finished product of the three different methods of casting employed. In the first comparison group (M1–M5), the effect of chilling rising steel on top without deoxidisation was to produce a spongy, segregated structure at the top of the ingot, whereas piping was reduced to a minimum. In this group the percentage of chemical to physical discard necessarily made thus was as 60·4 to 3·8, with a total of no less than 64·2 per cent. discard. The best results were secured in the second group (M6–M10), where the chilling of rising steel deoxidised with 2 oz. of aluminium per ton in the mould gave a proportion of 24·0 per cent. chemical to 5·8 per cent. physical discard, or 29·8 per cent. in all. In the third group the effect of deoxidisation on quiet or "killed" steel, without chilling, was expected to and did result in severe piping; the necessary discard on account of physical defects was therefore as high as 31·1 per cent. in this case, as against only 4 per cent. chemical discard on account of segregation. The total discard from the comparison ingots averaged 30 per cent. for chemical and 14·1 per cent. for physical reasons, the general average being 43·9 per cent. as against 18·4 per cent. in the case of the sink-head ingots. When it is remembered that nearly one-half the latter is due to the sink-head itself the value of the Hadfield process becomes apparent. As regards the rolled rails, 93 per cent. of "No. 1" rails were obtained from the Maryland ingots, but, as previously explained, the comparison between this figure and the 41 per cent. from the sink-head ingots is not emphasised.

Careful physical tests were made of all the steel used and revealed in both the sink-head and comparison ingots a uniform type of steel. The first sound 5-ft. length from each ingot was taken as a falling weight test-piece, a tup of 2,000 lb. being dropped from a height of 18 ft. on to the centre of the rail, which rested on supports 3 ft. apart. Details were taken of the permanent set, elongation of the base, and the number of blows required for the destruction of each rail; for the latter the 35 Hadfield rails required from two to seven blows, 63 per cent. withstanding four or more blows, whereas of the 14 comparison rails none broke under less than four or five blows.

For tensile, hardness and metallographic test purposes four 6-in. pieces were cut from different definite locations in each rolled-out bloom. The general average yield point in the case of the Hadfield steel was 28 per cent. and the ultimate tensile strength, 56·15 tons per square inch; measured on a gauge length of 2 in. the extension averaged 13·8 per cent. and the reduction of area, 24·38 per cent. The Brinell hardness number averaged 260 and the Scleroscope number 31. In the case of the Maryland ingots the average yield point was 27·4 per cent. and the ultimate tensile strength 55·6 tons per square inch, with an extension of 13·6 per cent. on 2 in., and a reduction of area of 25·78 per cent. Average Brinell hardness number in this case was 250 and Scleroscope number 32.

Other Tests.

An elaborate series of metallographic tests was also made, and threw additional light on the question of segregation and soundness, especially as regards the presence of slag inclusions, streaks and seams. The smoothness and evenness of tone of the sulphur prints of rails rolled from the Hadfield sink-head ingots was characteristic of all the prints made, and was in striking contrast to the markedly irregular prints obtained from the comparison ingot rails, some of which, from the bottom of the ingot, showed the existence of well-defined pipes. In the matter of microstructure the rails from the sink-head ingots also showed the greater uniformity, especially as regards the upper portion of the ingot, where the superiority of the sink-head type was to be expected. The general structure of the steel in both cases was, however, fairly uniform, except that in the comparison rails the ferrite network is less pronounced, and in some cases almost absent. In addition, a detailed chemical examination was made of a sink-head ingot and of sink-head and comparison blooms, which were split in half longitudinally for this purpose. Although there was a high degree of segregation at the extreme top of the sink-head ingot, it was proved that about 9 per cent. discard would leave a steel entirely free from piping or appreciable segregation. Sulphur prints taken from the sink-head bloom showed an even tone throughout, as compared with decided irregularities in the case of the comparison bloom; the latter, in addition, had an enclosed pipe extending to 12 per cent. below the top.

A chemical survey showed the analyses of both blooms as fairly uniform all through, except as regards sulphur in the comparison bloom, which, at a point even 21 per cent. from the top was as high as 0·12 per cent.

The rails manufactured during these tests were laid at two different locations on the Pennsylvania system, where a very heavy traffic is carried; at the first, after 11 months wear, the Hadfield rails had lost by abrasion 0·42 sq. in. of their cross-section, and the Maryland rails 0·37 sq. in.; at the second the rails were still in service at the same date, and the loss was then 16·1 per cent. for the Hadfield rails and 9·7 per cent. by the Maryland rails. The latter were, therefore, evidently capable of the harder wear, although the report admits that this superiority is probably due to their nickel-chromium content, which is absent in the case of the rails from the sink-head ingots. Emphasis is also placed on the fact that it would be unfair to draw any general conclusions as to relative performance in service from so few rails as this investigation furnished. None of the Hadfield or the Maryland rails had failed during their period of service, but a limited test of this nature was not conclusive.

Conclusions of Report.

In conclusion, the report establishes the fact that, after removal of the top discard of 13 per cent., the Hadfield type of sink-head ingot is free from piping and undue segregation, whereas the ordinary type of ingot, cast small end up without sink-head, as is usual in the case of rail ingots, requires an average top discard of 26 per cent., and even then the remainder of the ingot is liable to contain enclosed piping and excessive segregation. Existing specifications contain no provisions designed to safeguard the purchaser against such defective conditions, and as a result piped or excessively segregated rails may get into service, with possibly disastrous results. Further, the markedly differing characteristics displayed by the three heats of the comparison ingots, as a result of the different methods of casting employed, suggest the desirability of specifying, in at least some degree, the methods of steel manufacture or of ingot practice for rails or similar products on which the safety of the travelling public so largely depends. The report adds that, while it could not be claimed that the use of the sink-head process for the manufacture of steel ingots would solve all rail problems, its adoption would be a step in the right direction in view of the present heavy casualties and property losses, as a result of rail failures, on American railroads. It is believed that the necessary changes in mill operations could be made without serious difficulty.

Indian Railway Gauge Problem—*(continued from page 457).*

of the Railway Board, Sir R. Gillan and Sir Robert Gales, respectively* :—

1. Railways may be divided into two classes, through communications and "feeders."
2. For the former, the broad gauge has the advantage over the metre, and continuity of gauge is of great importance.
3. Hence—
   (a) When a new line is proposed alternatively on the broad and metre gauge, in territory which is not already definitely in possession of the metre gauge, the burden of proof of advantage should be on the metre gauge.
   (b) When the capacity of a single metre gauge line adjoining a broad gauge is exceeded, the presumption should be in favour of conversion, or of building an alternative broad gauge line, in preference to doubling.
4. It is unnecessary to aim at connecting up metre-gauge systems throughout India.
5. In the case of feeder lines: (a) Continuity of gauge is of less importance. (b) On the other hand the introduction of a break of gauge is not a proper method of preventing competition with main lines.
6. A system of "light railways" should be contemplated. These should be of the lightest standard and the cheapest gauge.
7. Local railways may be either of narrow gauge or of the gauge of the present line, depending on local circumstances.
8. A definite plan of All-India railway development should be drawn up.

* Indian Railway Board Technical Paper No. 212, p. 29.

The author would go further and say that not only is an All-India gauge policy required, but that legislative machinery is required to put it into force. For experience shows that if gauge questions are to be decided on their supposed merits by a changing *personnel*, there will never be consistency of action.

The author's proposal is that the Railway Act should be amended and enlarged as so to include a section dealing with the gauge question. The provisions of this section might be somewhat as follows :—

1. This section of the Act shall apply to all parts of India, except Burma and Assam.
2. The 5-ft. 6-in. gauge shall be the standard gauge.
3. Any railways or portions of railways under the operation of this section of the Act not conforming with such standard gauge shall be converted to that gauge when, in the opinion ot the Governor-General in Council, such conversion is required in the public interests.
4. The construction of all new railways shall be on the standard gauge, except as may hereinafter be provided.
5. Subject to the operation of Clause 3 :—
   (A) Lines of light traffic, when cheapness of first cost is an important consideration, may be constructed on the 2-ft. 6-in. gauge, or on the 2-ft. gauge in the case of extensions of existing 2-ft. lines.
   (B) A new line may be constructed on the metre gauge only on the following conditions:
      (a) That it is an extension of an existing metre-gauge line;
      (b) That it does not connect with or cross over, a standard-gauge line.

   N.B.—Under this sub-head, connection means the provision of direct tranship arrangements.