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ORIGINAL PAPERS.

THE USE OF FERRO-TITANIUM IN BESSEMER RAILS.

By P. H. DUDLEY.

The writer calculated and tested experimentally a formula for the use of ferro-titanium for Bessemer rails, to augment the average toughness and ductility of those of 0.50 in carbon and 0.096 in phosphorus, in connection with the New York Central Lines—1908 specifications. The use of Bessemer rails with practically 0.10 in phosphorus with as low carbon as mentioned under high-speed trains was not a matter of choice, but of stern necessity. It has been the expectation of Bessemer steel manufacturers and railroad officials for some years that owing to the exhaustion of the low phosphorus ores basic open-hearth rails would replace Bessemer, as the latter replaced iron less than half a century since. Several basic open-hearth plants have been installed and out of about 45,000,000 tons of rails in our tracks 2,000,000 tons are basic open-hearth. It was generally considered a simple problem to make the basic open-hearth rails of even 0.75 to 0.85 in carbon, but under 0.03 in phosphorus, and still secure immunity from rail fractures and failures, therefore, it was expected by the use of basic open-hearth rails that the fractures common to Bessemer steel would be eliminated.

The practical results of many fractures and failures in the new metal modified opinion and it will require time for a return to the conditions of manufacture which must be observed.

The chemical composition of 0.75 to 0.85 in carbon, with the accompanying manganese advocated at first as safe, forms in many cases a eutectic mixture in which the ferrite is apparently all absorbed, the ductility of the steel being low, hard and sensitive to shocks. The saturation point of the ferrite by carbon has been considered as 0.90, but in rails and tires with the manganese content it seems often ten to twenty points lower, and traces of cementite may occur. A carbon content of 0.62 to 0.75, with greater ductility, is considered more reliable in rails as girders.

The demand for basic open-hearth rails in 1907 and 1908 was far beyond the capacity of the plants to fill. Therefore, but few railroads were able to secure sufficient rails of that class of steel for their requirements and others had to be content with a small tonnage for trial. This compelled me to reinstate former Bessemer principles of practice which had been lost in the great demand for output, and also to try additional means for better Bessemer rails for modern heavy wheel loads and high-speed trains. I did not expect or consider that my method for the use of ferro-titanium would be generally used by the railroads for the Bessemer departments of all manufacturers were not so arranged that they could follow all the details but would be obliged to resort to more expensive methods.

The results of the first service tests seemed so satisfactory to other railroad systems that they wished to try similar rails and several trial orders were placed for 1,000 to 5,000 tons, distributed over a great extent of country. The rails passed through the unusually severe winter of 1909 and 1910 with favorable comparisons.

I have answered many inquiries in reference to my rails, but have been reluctant to answer requests for publication until I could have the results of the service of two winters to see whether or not they agreed and sustained the calculations and preliminary physical tests.

Five thousand tons of rails of the six-inch 100-lb. Dudley section were made in 1908 and sent to the Electric Division in New York City. These rails were laid in the autumn of 1908, and in May, 1910, not a single rail had broken. The plain Bessemer rails in the same section and location had heretofore

developed a number of fractures during the winters even for those having no higher content of carbon than the present rail in which ferro-titanium was used.

Seven thousand and five hundred tons of the same section were sent to the Boston and Albany Railroad and only three rails failed, two from injuries received in loading. While in three thousand tons of 80-lb. rails some of them laid in 1908, therefore, had two winters' service, not a rail fractured, which tends to corroborate the calculations and preliminary tests. The equally as good comparative results on other railroads beside the New York Central lines are further confirmation that some increase in purity, toughness and ductility of the metal has been practically secured.

The problem in the manufacture of rails for high-speed trains at the present time is to obtain a higher average purity, toughness and ductility for the metal of all the heats than was required fifteen and twenty years ago, before the advent of the present heavy wheel loads and high-speed trains. The five-inch 80-lb. rail which I first designed for the New York Central & Hudson River Railroad, in 1883, the phosphorus content was 0.08 with 0.45 to 0.50 in carbon. Some of these rails proved fragile in the track after a few years' service under the high-speed trains which were inaugurated after the introduction of that section. When I made the revised $5\frac{1}{8}$ in. 80-lb. and six inch 100-lb. sections, and also the Boston & Albany 95-lb. section in 1890, I knew from experience that it would be necessary to increase the carbon content of those rails for heavy service. To do this I limited the phosphorus to 0.06 in the metal and made the carbon content 0.56 to 0.65 in the Boston & Albany 95-lb. and the 100-lb. rails. These proved under the drop test to be not only tough, but the ductility ranged from 10 to 14 per cent. as secured for the most of the heats.

To make and test the rails in 1891 I had to reinstate the drop test and made it a part of the specifications that 90 per cent. of the butts should stand a drop of 2,000 lbs. falling 20 feet, supports three feet apart, and heats of butts which broke, though gave four per cent. maximum elongation per inch, would be accepted. The butts before testing were stamped in the center on the base or head, as desired, with a spacing bar of seven conical points, each one inch apart. These six-inch former spaces after the drop would be extended and were measured by a flexible steel rule divided in hundredths of an inch, therefore, the excess hundredths per inch gave the percentage of elongation. The range of ductility of the steel was designed to be between 8 and 15 per cent., excepting the small percentage of heats of which the minimum elongation must be 4 per cent. or over to be accepted.

The maximum elongation per inch for the 100-lb.

rail under the 40,000 foot pounds of energy of the drop was only five per cent. for its standard permanent set of 0.92 of an inch. Therefore, most of the energy of the drop would be expended upon the butt when the four per cent. elongation was produced per inch before the butt broke or sheared.

A shear was not treated as a broken butt in the rejection of heats for the valuable indications it gave were that the upper limit in chemical composition for a fine textured steel had been practically reached. The elongations were measured and considered in accepting or rejecting the heats. It takes but a few minutes now to describe the earlier results in the heavier sections, but it was the work of years, first making the steel, rolling the sections, then taking yearly diagrams of the tracks by my Track Inspection Apparatus, and also studying the results of service for guidance in future work.

There were over 600,000 tons of the low phosphorus, 0.06, and high carbon rails made and in most of them the copper content ranged from 0.6 to 0.8 of one per cent., which, after the long service, is considered to have added to the toughness of the steel under the passing wheel loads as but a small percentage of the rails have broken after twelve to eighteen years of service. Since the exhaustion of the low phosphorus ores and the loss of the copper in the Bessemer rails for the same section, a greater decrease, proportionately, of the carbon has been required for the four additional points above 0.06, or 0.10 phosphorus in the metal. The minimum range of ductility for the higher phosphorus without copper must be six to seven per cent. instead of the former minimum of four per cent. with copper.

The high phosphorus content of 0.10 constitutes the greatest objection to-day to the use of such Bessemer rails for heavy traffic and is one reason why I am trying to make them better by the use of ferro-titanium.

Phosphorus makes steel brittle to shocks as it hardens it, which limits the carbon to about 0.50 for heavy sections, where they are to be used in temperatures which fall 10° – 20° F. below zero in the winter months. The brittleness in the early Bessemer steel rails was attributed principally to the phosphorus content even with the low content of 0.30 to 0.40 carbon. It seemed to be erratic, or such effects were attributed to phosphorus, for it was found to exist in two or more forms in the steel, one form being considered harmless and another detrimental. This is not considered proven in practice, as all high phosphorus metal in rails has fractured more than low phosphorus Bessemer rails. The early sections of steel rails were rolled only $3\frac{1}{2}$ inches to $4\frac{1}{4}$ inches in height from small ingots and segregations of carbon and phosphorus were elongated and diffused more than is the case of heavier rails from large ingots.

Sections of 52-lb. rails, which wore well under the light service, though some rails fractured, have been found recently which contained 0.14 and 0.16 phosphorus in two different brands of rails. These light sections had small mechanical properties, were flexible in the track and could not carry large bending moments, therefore there was more time to distribute the strains of the passing wheel loads through the metal of the section than there is in the present heavy stiff sections, carrying larger bending moments to reduce the undulations and train resistance of the track.

The first experiments of the use of ferro-titanium in the metal the ingots were better and the steel showed an increased purity, toughness and ductility. The same carbon content, compared with the plain Bessemer steel in the same sections the ductility averages higher and runs more uniform for a larger number of heats than it has been possible to secure in ordinary Bessemer. The ferro-titanium as a subsidiary deoxidizer, besides reducing a greater percentage of oxides of iron in the steel, also reduces a portion of the nitrogen, which decreases the brittleness and thus adds to the toughness of the steel. The nitrogen content seems to be small in some heats, but higher in others, and by the use of ferro-titanium a more uniform range of ductility has been obtained in the steel.

The nitrogen content reported in some of the 1904 Bessemer rails which broke was 0.0147 to 0.0153, and in others which did not 0.003 to 0.006, according to determinations which I had made in 1906. These were considered as comparative indications rather than as accurate determinations which can now be readily and more cheaply made. It is considered as a working hypothesis that the nitrogen content in steel reduces the ductility five times faster than phosphorus and fifteen times faster than carbon in large sections of rails subjected to shocks. These comparisons will be checked for rectification as data is gathered in reference to nitrogen. The use of ferro-titanium shows a reduction of the nitrogen content in steel after its use and an increase in the toughness, besides a greater reduction of the oxides of iron.

Plotting the results of the elongation of the drop tests has been of invaluable service to me in rail manufacture for high-speed trains. The ductility of the steel in the full-sized section can be exhausted in two or more blows under the present Manufacturers' Standard Drop Testing Machines, the butts being stamped in inches before testing, as already described. The elongation of the metal under the drop testing machine compares favorably with that obtained by static loads in the testing machine. The tendency is an increase of possibly two or more per cent., owing to the fact that the base of the rail which

stretches does not neck as in the case of a tensile specimen. It is also probable that the energy converted into heat, and the rising temperature of the butt, under successive blows, slightly increases the ductility of the metal. The possibility of determining quickly the ductility of the metal in the section from hour to hour as rolled is one of great value, as conditions of manufacture can be followed as they occur.

A 100-lb. rolled section of pure iron, before exhaustion of ductility, would show under the drop an elongation of 45 or 50 per cent. for two or three inches directly under the point of impact. By adding carbon and manganese to the iron, increasing the physical properties of the metal, there is, as expected, a reduction in the elongation of the metal. The content of impurities of phosphorus, sulphur, nitrogen, arsenic and oxides that will make further reductions of elongation and should be considered in the chemical composition for service as girders or to harden the metal to resist abrasion for slow trains.

Fig. 1 shows a chart of the records plotted of the drop tests of 224 heats of 90-lb. Bessemer rail A. S. C. E. Section, rolled in March, 1910. The horizontal lines on the charts with their figures indicate

Fig. 1.—Consecutive drop tests.
90-lb. Rails, A. S. C. E. Section.
Bessemer: C, 0.44; Mn, 0.90; P, 0.095; Si, 0.13.

the percentages of the elongation and ductility while the vertical lines and figures the heat numbers. The chemical composition of the steel averaged 0.44 in carbon and 0.096 in phosphorus, the manganese being nearly one per cent. These rails were intended for a high average range of ductility as girders and therefore are on the soft side for wear.

The maximum elongation per inch under the drop of 2,000 lbs. falling 17 feet was 7 per cent. The elongation for a single blow for all the heats is definite, for each butt withstood the drop and retests were not required in a single case. This percentage is shown by a line of dashes and dots marked 7 per cent. Therefore, the minimum ductility of every heat is above the 7 per cent. line. There were thirteen of the butts distributed through the heats and the ductility exhausted completely to find the maximum for the metal. These are plotted on the charts by a line of dots with circles, the latter to indicate the heats which were tested.

It is not possible in regular work of the mill to have the drop testing machine sufficient time to exhaust the ductility in every heat, but only of a few to show the elongation in the general run of the steel. It is probable that there would be some heats which were not exhausted completely that the minimum ductility would be less than the 12 per cent. shown for the five heats, but it would be above 7 per cent.

Each of the five heats, beside standing the first blow, required a second to break them, the elongation being about 12 per cent. and is shown by a horizontal line of short dashes. The two circles in the first group of 40 heats indicate there were two tests which required five blows to exhaust the 28 per cent. ductility, and then a heat broke under two blows with the 12 per cent. elongation. Three butts in each of the following groups of 80 heats also gave 23 per cent. ductility. The following 15 heats are represented by two butts which broke at the second blow, but each gave about 12 per cent. elongation.

The plotting of the group in this manner is to obtain a general indication of the elongation and ductility during a turn of twelve hours, or two turns in twenty-four hours' work, and this is above the average for Bessemer rails.

The charts of the drop tests plotted in this manner show positively the ductility of every heat secured by one blow of the drop, and of the others in which the ductility is completely exhausted. While the permanent sets under the drop have been recorded, it has not been usual to measure the elongation of the metal per inch in the section except in my practice.

To compare the ductility of individual heats or melts, tests are made exhausting the ductility by two or more blows. These are shown by Figs. 2 to 7, inclusive. The graphic representation of each heat of melt in the figures is shown, as will be seen, from the percentage marks per blow and are represented by vertical lines of about one-fortieth of an inch ($1/40''$) in thickness; two blows double that thickness; three blows three times; and four blows by one-tenth of an inch ($1/10''$). The different steps shown on the chart gives the percentages of ductility obtained at each blow, while a double width of the top indicates that another blow was required to break the butt, though additional elongation was not produced. The horizontal lines in the diagrams with their figures indicate the percentages of elongation.

Fig. 2 shows elongation and ductility tests of plain Bessemer steel rolled June 14 and 15, 1909. The heats Nos. 14793 and 14925, represented by the first and second graphs, were tested March 28, 1910, drop 17 feet. The steel was intended for a range of ductility of 10 to 15 per cent. and required three blows of the drop to break the butts.

The heat No. 31703, represented by the third graph, was rolled September 18, 1909, and tested March 28, 1910, drop 17 feet. The object of holding these butts was to see about the removal of the initial

Fig. 2.—Ductility tests.
100-lb. rails, Dudley Section.
Bessemer: C, 0.50; Mn, 1.00; P, 0.096; Si, 0.13.

strains of rolling after six to eight months of manufacture. The butts were reserved on skids under cover at the mill but had not been handled. It had been noticed several times that groups of butts which stood the drop test on the day of manufacture or a day thereafter, that when some were laid aside on the ground four or five weeks they did not stand the drop test, but some of the same butts, after three to six months, usually stood the test, the belief being that the initial strains of rolling had by time become better equalized. I cite this as a coincidence which occurred with the author twice, and others have had similar coincidences, but these do not establish a general law, as the manner of storing is now believed to be an important factor.

New steel rolls, after turning to dimensions, are safer from breaking by "seasoning" six to eight months before using, for a large amount of metal has been removed from the exterior diameter and the interior strains require time or change of temperature to become equalized.

Fig. No. 3: Heat Nos. 17571 and 17575, represented by the first and second graph, were rolled June 1, 1909, for the Detroit River Tunnel Co. These had a discard of 19 per cent. and were tested March 29, 1910. The third graph was the same

Fig. 3.—Ductility tests, 100-lb. rails.
F. T. Bessemer: C, 0.50; Mn, 1.00; P, 0.095; Si, 0.13.

section rolled May 1, 1909, but tested the same date as the others. These were ferro-titanium rails to have a range of 15 to 20 per cent. ductility. Height

of drop 17 feet. The section was the A. S. C. E. 100-lb.

It did not make any difference when these butts were tested, they proved tough and at any time requiring five blows for the first two and six for the third, which was a 9 per cent. discard three-rail ingot. The other two ingots were from the same molds but three-rail ingots with more discard.

Graphs fourth and fifth show the B and C rails of heat No. 39926. The B rail required three blows to break and had 14 per cent. ductility. The C rail required four blows and had a ductility of 18 per cent. These were 100-lb. rails with a chemical composition to have a range of 10 to 15 per cent. ductility. The sixth graph was a condemned A rail for a blistered web. The ingot was delayed in charging into the reheating furnace until a large shrinkage cavity formed and the section failed the second blow from mechanical weakness, due to the shrinkage cavity. It stood the one required blow, therefore would not have been detected except for the blistered web. Any interruption to the regular mill practice as an

Fig. 4.—Ductility tests.
5 1/2-inch 80-lb. rails, Dudley Section.
F. T. Bessemer: C, 0.49; Mn, 0.96; P, 0.096; Si, 0.13.

ingot car off the track, a "sticker" at the "stripper," or an extra run to the gantry, will affect the setting of an ingot or a heat of ingots, more decidedly the greater the purity of the steel.

Fig. No. 4 represents the Dudley section of 5 1/2 inch 80-lb. rails, rolled from four-rail length ingots which are about 350 lbs. heavier than the three-rail length for the 100-lb. rails, while the chemical composition is practically the same, the range of ductility being only 10 to 15 per cent. to resist curve abrasion. Ferro-titanium raised the minimum ductility by three to four per cent. in these rails.

The heat No. 8704 shown by the first graph was condemned by the maker on account of being too high in carbon, yet it shows 9 per cent. of ductility. It would have been an excellent rail to resist abrasion upon curves under slow traffic. The other twelve heats from No. 16195 to 16224 were all rolled March 29, 1910, and tested April 14th. The lowest range is 10 per cent. ductility, while the majority show over 18 per cent., one heat showing 25 per cent., all heats requiring two or more blows of 16 ft. to exhaust the ductility. This wide range is interesting and reflects

the change from a medium rolling temperature to one a few degrees lower, by a reduction of ductility, though in none of the examples below the safe limit of 10 per cent. elongation and required two blows to break the butts. Fig. 5 shows heats of plain Besse-

Fig. 5.—Ductility tests.
100-lb. rails, A. S. C. E. Section.
Bessemer: C, 0.50; Mn, 0.98; P, 0.96; Si, 0.13.

mer steel in 100-lb. rails intended for a range of 10 to 15 per cent. ductility. Two of the heats gave only 7 and 8 per cent. elongation under two blows each, a third 11 per cent. elongation for the second blow, while one heat gave 18 per cent. elongation and required four blows to break the butt. These were nearly consecutive heats and show quite a range in the ductility often observed in plain Bessemer steel.

Fig. 6 shows the elongation and ductility of 100-lb. New York Central rails, Dudley 6-inch 100-

Fig. 6.—Ductility tests.
100-lb. rails, Dudley Section.
F. T. Bessemer: C, 0.50; Mn, 1.00; P, 0.096; Si, 0.13.

lb. section. These were designed for a range of ductility of 10 to 15 per cent. All of the heats required three blows to exhaust the ductility and none broke under 11 per cent. elongation.

Fig. 7 shows a number of heats of open-hearth

Fig. 7.—Ductility tests.
100-lb. rails, A. S. C. E. Section.
B. O. H.: C, 0.68; Mn, 0.86; P, 0.012; Si, 0.10.

rails with carbon about 0.69 with the phosphorus under 0.03. These were intended for a range of ductility of 12 to 18 per cent. for use under high-speed trains where the temperature in winter falls 10 to 30 degrees F. below zero. Rails of similar composition have been in service three and four years with comparatively few fractures.

Correlation of the Equipment and the Tracks.

The equipment and track are of necessity so intimately correlated that for high-speed trains of heavy loads the wheels need tires of higher physical properties and maintenance than formerly required. The tires under the heavy wheel loads do not all wear uniformly the entire circumference of the tread, soft spots developing in a portion and the wheels become eccentric, increasing the dynamic shocks upon the rails each revolution. The metal in tires under the heavy loads and high-speed trains is more severely strained and abraded than in the past, and it will require as thorough consideration of the comparative methods of manufacture as has been exercised for rails.

The tonnage upon the tread of a tire accumulates with great rapidity. The 36-inch wheel makes 560.2 revolutions per mile, therefore, every portion of the metal of bearing surface of the tread is subjected to its static load 560.2 times per mile, and for a static load of five tons it would be equivalent to 2,801 tons per mile, beside the generated wheel effects.

The accumulated tonnage exclusive of the generated wheel effects for a static load of five tons per wheel in a trip from Boston to Chicago would be 2,865,423 tons; New York to Chicago, 2,700,164 tons; New York to St. Louis, 3,243,558 tons; New York to Cincinnati, 2,478,885 tons. A tender wheel with an average static load of nine tons, or 5,041.8 tons per mile, the tonnage for a trip of 150 miles would be 756,270 tons and run in about three hours and fifteen minutes. The generated wheel effects would be from 20 to 50 per cent. additional in all cases, depending upon how smooth or even the treads maintained their circumference, speed, and also the smoothness of the track. A tender wheel became eccentric for a space of about ten inches in the tread after it had run 29,000 miles and its total tonnage approximated 146,000,000 tons in about six months' service. Some tires become eccentric after running 10,000 to 15,000 miles. The tires are subject to greater tonnage than rails in a given length of time. Years are required for the rails to carry as heavy tonnage as the tires do in a few months, the latter being returned for further duty. It requires a metal of high elastic limits of the steel to sustain the treads without undue wear.

CONCLUSIONS.

1. The illustrations of the elongation and ductility

tests indicate the possibility that from a well studied chemical composition for steel rails with good fabrication a range of ductility in reference to great toughness can be prescribed for the different sections to meet conditions of service as girders for high speeds, or with more hardness but less ductility, to resist curve abrasion and wear at slow speeds.

2. Rails which are to be used in low temperatures under high-speed trains the toughness and ductility of the metals must have preference over hardness, particularly of that high in phosphorus, as the latter limits the amount of carbon which can be used to resist abrasion and wear, and still be safe as girders.

3. The carbon in basic open-hearth rails should be below the eutectic mixture of the chemical composition for high-speed trains, as otherwise the toughness and ductility may be reduced to a condition of brittleness in many rails.

4. The average ductility in Bessemer rails of 0.50 carbon and 0.095 in phosphorus has been raised two or three per cent. by the use of ferro-titanium in the steel as practically shown by one and two winters' service, and is considered worthy of further trials.

Ferro-titanium has a direct action upon the purification of the metal and setting of the ingots, and must, therefore, be used with a knowledge of what is desired, to secure the best results.

5. The problems of rail-making for service in the United States are now upon a better basis than ever before, owing to the coöperation of the railroad companies and the manufacturers to secure rails which are suitable for the present traffic. This arises from a more general knowledge of what is required than was understood a few years since.

[CONTRIBUTION FROM PITTSBURG LABORATORY, TECHNOLOGIC BRANCH,
UNITED STATES GEOLOGICAL SURVEY.]

SOME VARIATIONS IN THE OFFICIAL METHOD FOR THE DETERMINATION OF VOLATILE MATTER IN COAL.

By A. C. FIELDNER AND J. D. DAVIS.¹

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In view of the proposed revision of the official methods of coal analysis, it may be of interest to present certain experimental data bearing on the present official method for the determination of volatile matter in coal.

These experiments were conducted in the Pittsburgh and Washington laboratories of the U. S. Geological Survey, primarily to ascertain the difference in volatile matter produced by using a 20 cm. natural gas flame as compared with the 20 cm. coal gas flame. After starting the work it was found desirable to investigate the influence of other factors such as gas pressure, type of burner, and surface condition of

¹ Presented by permission of the Director, U. S. Geological Survey