RP408

TENSILE PROPERTIES OF RAIL STEELS AT ELEVATED TEMPERATURES

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ABSTRACT

In continuation of previously reported work on a study of transverse fissure failures in railroad rails, a further series of tensile tests at elevated temperatures has been made on a number of rails representing different conditions of manufacture and service to determine the extent to which secondary brittleness occurred in these materials. Slower cooling from the hot saw tended to reduce the secondary brittleness at some sacrifice of tensile strength. No difference in tensile strength or secondary brittleness was found between fissured and unfissured rails that had been subjected to the same service. No appreciable difference in ductility was found in rails made at a certain mill when their rails were yielding poor service records and rails made subsequently which had improved service records; although secondary brittleness was not marked in either series, the ductility was rather low in the higher temperature range. Shatter cracks were found in all rails examined, which had failed in service. Secondary brittleness was manifest in both used and unused sorbitized rails. Shatter cracks were found in both.

CONTENTS

I. INTRODUCTION

Failures in railroad rails have been of vital concern to engineers, railroad executives, rail manufacturers, and the general public for years. Failure from transverse fissures originating from internal nuclei, have received particular attention in the past 20 years. J. E. Howard first reported this type of failure in 1911 as being responsible for a wreck on the Lehigh Valley Railroad in which several lives were lost. Since then many transverse fissures have been found. In 1919 Waring and Hofammann[1] etched longitudinal sections of rails in hot acid and found cracks extending both longitudinally and transversely in certain used rails as well as in some new rails. Since then

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[1] F. M. Waring and K. E. Hofammann, Deep Etching of Rails and Forging, Am. Soc. Testing Materials, vol. 19, pt. 2, p. 183; 1919.

it has been thought by many that these "shatter" cracks are the nuclei from which transverse fissures subsequently develop in service. Methods for reducing the rate of cooling rails on the hot bed have been devised to decrease the temperature gradient and consequently the stress gradient in the rails. A study of the tensile properties of rails at elevated temperatures was made by Freeman and Quick,[2] who investigated the properties at temperatures through which rails pass on the cooling bed after leaving the hot saw. In their investigation a special study was made of the ductility of the steels in the temperature range 400° to 700° C. In this temperature range it was found that certain rail and other steels showed a marked decrease in elongation and reduction of area. The phenomenon was called "secondary brittleness" and the temperature range the "secondary brittle range." A tentative explanation was presented that internal failures, such as "shatter cracks" and "hair cracks" in rails, are the result of thermal stresses developed in the steel structure while cooling through the secondary brittle range. The investigation showed that the magnitude of the phenomenon varies for different heats, but that it did not differ for specimens from different ingots or for different rails in a particular ingot. It was also shown that annealing rail steel at a temperature, either above or below the critical range, markedly reduced the degree of the secondary brittleness. It was suggested that rapid cooling through the secondary brittle range was the cause of the formation of shatter cracks which, it was believed, were the nuclei of transverse fissures.

II. SCOPE OF PRESENT WORK

In 1929 arrangements were made for certain railroads to furnish the bureau with samples of rails for elevated temperature tensile tests. They included rails that had been cooled at different rates on the cooling beds; samples from fissured and unfissured rails; a new and a used sorbitized rail; a medium manganese rail deoxidized with zirconium; and rails from a particular mill, rolled prior to July, 1927, just after July, 1927, and at a more recent date. Many transverse fissures developed in rails rolled by this particular mill prior to July, 1927, and in rails rolled at a recent date, whereas in rails rolled just after July, 1927, relatively few fissures developed. A fissure had been discovered in the used sorbitized rail with the Sperry detector car.

This paper reports the results of elevated-temperature tensile tests on specimens from these rails. The procedure of testing was the same as described in the previous paper. Table 1 gives the designation, the chemical composition, and source of the materials studied.

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[2] John R. Freeman, jr., and G. Willard Quick, Tensile Properties of Rail and Other Steels at Elevated Temperatures, B. S. Jour. Research, vol. 4 (RP 164), April, 1930, p. 549; A. I. M. E. Iron and Steel Division, p. 225; 1930.

TABLE 1.—*Materials studied*

Designation	Chemical Composition					Remarks
	C	Mn	P	S	Si	
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
AL1	0.69	0.70	0.023	0.027	0.14	100-pound standard rail, heat No. 2435; cooled normally.
AL2	.69	.70	.023	.027	.14	100-pound standard rail, heat No. 2435; cooled slowly in mill scale.
PR1	.86	.65	.021	.038	.20	100-pound standard rail, heat No. 214562; cooled normally.
PR2	.86	.65	.021	.038	.20	100-pound standard rail, heat No. 214562; cooled slowly under a cover.
S1	.60	1.36	.027	.029	.13	120-pound medium manganese rail, heat No. 11588; cooled slowly in mill scale.
S2	.60	1.36	.027	.029	.13	120-pound medium manganese rail, heat No. 11588; cooled in air until magnetic, then mill scale.
S3	.60	1.36	.027	.029	.13	120-pound medium manganese rail, heat No. 11588; cooled normally.
S4	.54	1.51	.018	.025	.17	120-pound medium manganese rail, heat No. 6523; cooled slowly in mill scale.
S5	.54	1.51	.018	.025	.17	120-pound medium manganese rail, heat No. 6523; cooled in air until magnetic, then mill scale.
S6	.54	1.51	.018	.025	.17	120-pound medium manganese rail, heat No. 6523; cooled normally.
S7	.78	.85	.026	.036	.19	120-pound standard rail, heat No. 43050; cooled slowly in mill scale.
S8	.78	.85	.026	.036	.19	120-pound standard rail, heat No. 43050; cooled in air until magnetic, then mill scale.
S9	.78	.85	.026	.036	.19	120-pound standard rail, heat No. 43050; cooled normally.
S10	.77	.82	.029	.034	.28	120-pound standard rail, heat No. 55013; cooled slowly in mill scale.
S11	.77	.82	.029	.034	.28	120-pound standard rail, heat No. 55013; cooled in air until magnetic, then mill scale.
S12	.77	.82	.029	.034	.28	120-pound standard rail, heat No. 55013; cooled normally.
LN1	.76	.75	.039	.051	.18	100-pound rail, heat No. 874163; rolled January, 1927.
LN2	.75	.72	.025	.055	.22	100-pound rail, heat No. 815420; rolled January, 1928.
LN3	.83	.77	.033	.037	.23	100-pound rail, heat No. 885445; rolled December, 1928.
MP1	.74	.76	.020	.052	.20	85-pound rail, heat No. 856284; rolled 1926, A rail.
MP2	.77	.73	.018	.021	.18	90-pound rail, heat No. 829732; rolled 1929, G rail.
NC	.74	.91	.026	.035	.24	90-pound rail, heat No. 42249; rolled December, 1924, C rail.
CP1	.66	1.00	.072	.037	.14	Used standard rail, fissured.
CP2	.68	1.02	.039	.038	.11	Used standard rail, not fissured.
DL1	.68	1.40	.019	.022	.35	Used 130-pound medium manganese rail, fissured.
DL2	.70	1.36	.025	.015	.55	Used 130-pound medium manganese rail, not fissured.
DH1	.77	.74	.022	.030	.30	New 90-pound sorbitized rail, heat No. 86607, C–5.
DH2	.82	.79	.011	.029	.24	Used 90-pound sorbitized rail, heat No. 86666, C–11. Fissure detected by Sperry detector car.
K [1]	.65	1.59	.014	.032	.32	New 130-pound medium manganese rail, deoxidized with zirconium; F rail.

[1] Zr 0.09 per cent.

III. RESULTS OF ELEVATED TEMPERATURE TENSILE TESTS

1. EFFECT OF DIFFERENT RATES OF COOLING

Some of the first 16 materials listed in Table 1 were cooled in the normal way from the hot saw, whereas comparison rails from the same heats were cooled at a slower rate. Specimens from these rails were tested in tension at temperatures ranging from room temperatures to 700° or 750° C. Rails AL1 and AL2 were new rails from the same heat. Rail AL1 cooled on the hot bed in the normal manner showed blue brittleness in the range 200° to 300° C. with improved ductility at 400° C. At 550° and 600° C., secondary brittleness was quite marked and above 600° C., the ductility increased. The results were similar to many reported previously.[3] Rail AL2 from the same heat after leaving the hot saw was cooled slowly by burying in mill scale. The slower cooling caused a reduction of from 5,000 to 10,000

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[3] See footnote 2, p. 174.

lbs./in.^{2} in tensile strength throughout the range of the elevated temperature tensile tests. There was less difference between the maximum and minimum elongation and reduction of area for the slowly cooled rail than for the normally cooled rail from 300° to 700° C. The results of the tests on rail steels AL1 and AL2 are given in Figure 1. The higher ductility of AL2 in the secondary brittle range was similar to the effect of annealing at 1,000° and 700° C. previous to testing as reported in the previous paper.[3]

Rails PR1 and PR2 were 120-pound rails which had been in service. PR1 was cooled from the hot saw in the normal manner and PR2 was cooled slowly under a preheated hood. The results of tests on specimens from these rails plotted in Figure 2 show that the manner in which the curves were modified by slow cooling was similar to those given in Figure 1 for AL1 and AL2.

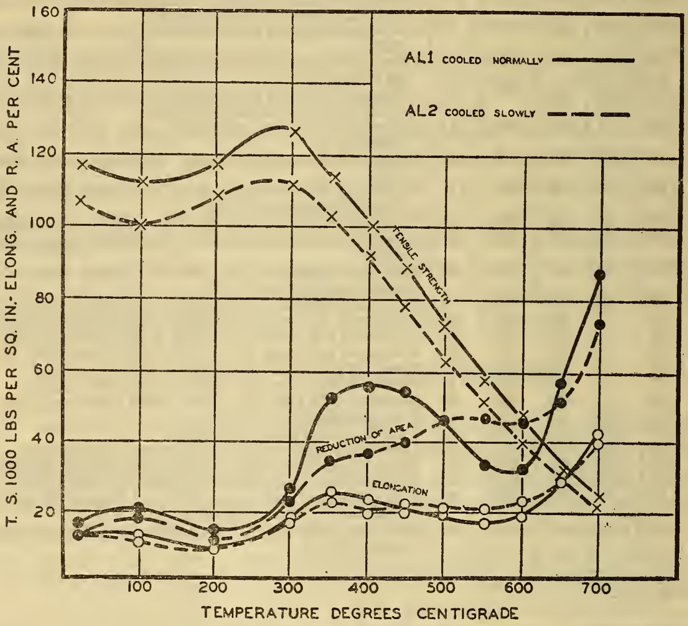

FIGURE 1.—*Results of tensile tests of specimens from new rails of the same heat*

AL1 cooled normally and AL2 cooled slowly in mill scale from the hot saw.

Three samples of rails from each of two duplicate heats of medium-manganese rail steel (S1 to S6, inclusive, Table 1) and three samples from each of two duplicate heats of standard rail (S7 to S12, Table 1), were secured through the courtesy of the test department of the Atchison, Topeka & Santa Fe Railroad. One sample from each heat had been cooled normally from the hot saw, one was cooled while buried in mill scale, and one was cooled in air until the head became magnetic and then buried in mill scale. The third method of cooling will be referred to as "interrupted cooling." Records of the temperatures of the air in the mill and the rails were not obtained for the medium manganese rails, but for the standard rails the following information was obtained: The atmospheric temperature of the mill

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[3] See footnote 2, p. 174.

was 14° F. The temperature of the rails when they came through the finishing pass was about 1,950° F. The temperature at which the rails became magnetic when cooled in air was determined with an optical pyrometer to be between 1,275° and 1,300° F. The rails were uniformly heated and were handled in accordance with the best rolling-mill practice. The pieces that were buried in scale had about 3 inches of scale under them and at least 4 inches above the top of the head. The tensile strength of the more slowly cooled medium-manganese rails was lower than that of the normally cooled rails (figs. 3 and 4), from room temperature to 400° C., but above 400° C. the effect of slow cooling was not so noticeable. The results plotted in Figures 5 and 6 for the standard heats show that the tensile strength of the more slowly cooled rails was lower than that of the normally cooled rails over the entire range of test.

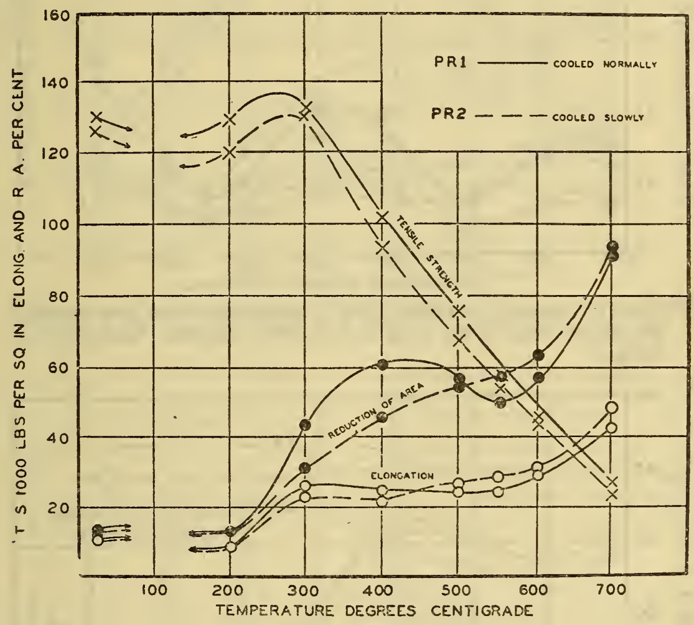

FIGURE 2.—*Results of tensile tests of specimens from used rails of the same heat*

PR1 cooled normally and PR2 cooled slowly under a preheated hood from the hot saw.

The tensile tests at elevated temperature on the standard rails (S7–S12) did not show as marked secondary brittleness for the normally cooled rails as was shown for the normally cooled AL and PR rails or the medium manganese rails (S1–S6). This is seen by comparing Figures 1 and 2 with Figures 3, 4, 5, and 6. The ductility curves of the rails cooled slowly (in mill scale) did show less difference between maximum and minimum from 300° to 700° C. than those of the rails cooled normally. The ductility curves of the medium-manganese rails after "interrupted cooling" followed closely those for the medium manganese rails cooled normally (figs. 3 and 4), whereas the ductility curves of the standard rails cooled in the same manner followed closely those for the standard rails cooled in mill scale (figs. 5 and 6). This

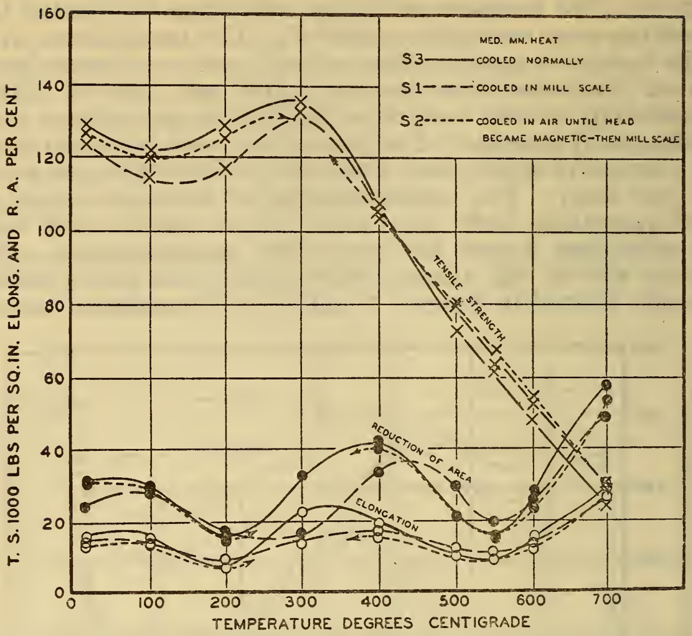

FIGURE 3.—*Results of tensile tests of specimens from new medium manganese rails of the same heat cooled at different rates from the hot saw*

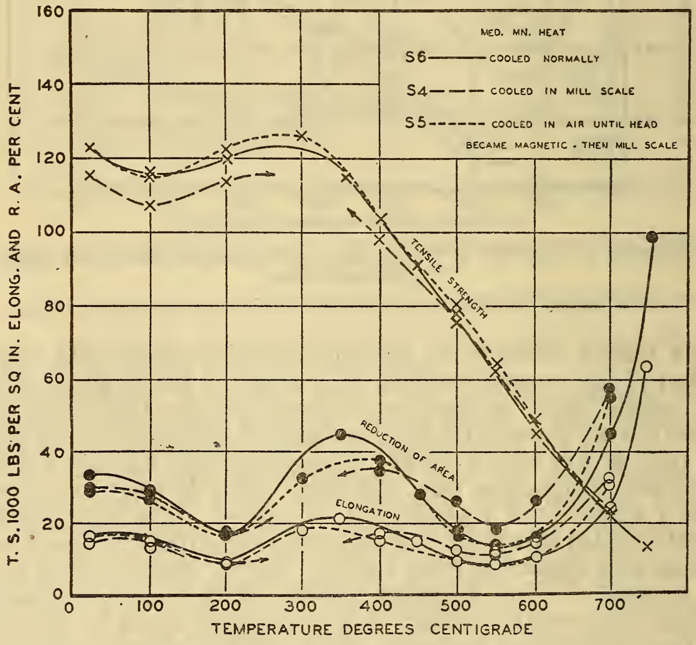

FIGURE 4.—*Results of tensile tests of specimens from new medium manganese rails of the same heat cooled at different rates from the hot saw*

This was from a duplicate heat to the one given in Figure 3.

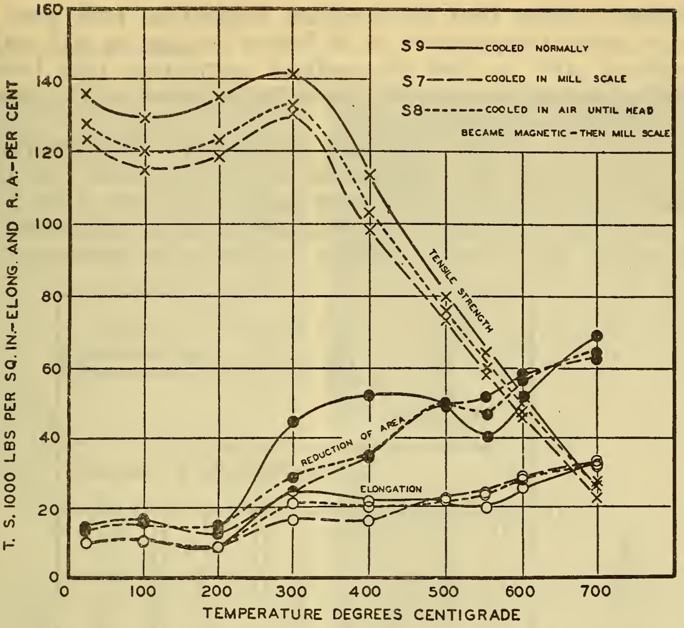

FIGURE 5.—*Results of tensile tests of specimens from new "standard" rails of the same heat cooled at different rates from the hot saw*

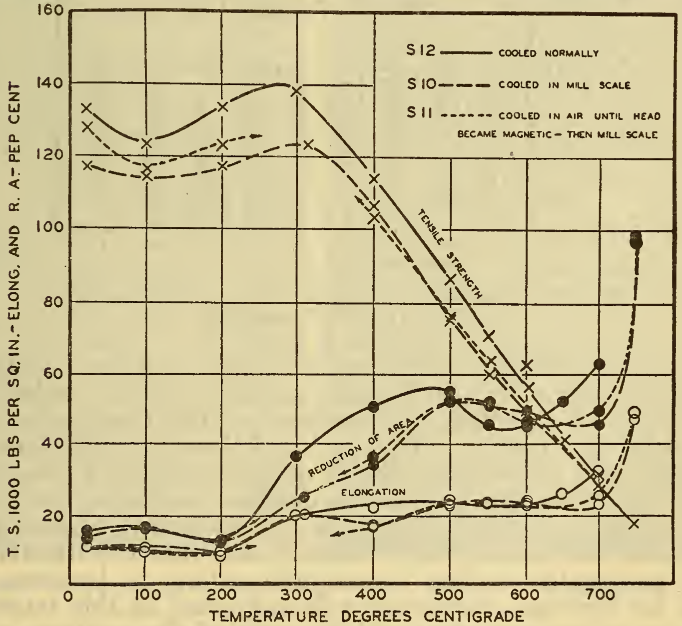

FIGURE 6.—*Results of tensile tests of specimens from new "standard" rails of the same heat cooled at different rates from the hot saw*

This was from a duplicate heat to the one given in Figure 5.

may indicate either that the medium manganese rails were cooled to a much lower temperature in air before burying in mill scale than the standard rails, or that the medium manganese rails because of their higher manganese content, were less affected by this somewhat slower cooling from the hot saw.

The structure of the steel was modified by the slower cooling. Figure 7 shows that the structure of the slowly cooled rail AL2 was better developed and the pearlite was coarser than that in the normally cooled rail AL1; also, there was evidence of spheroidization in some of the slowly cooled rails. Figure 8 shows the structure of rails PR1, cooled normally, and PR2, cooled slowly, and also the structure of medium manganese rails S6, cooled normally, and S4, cooled slowly.

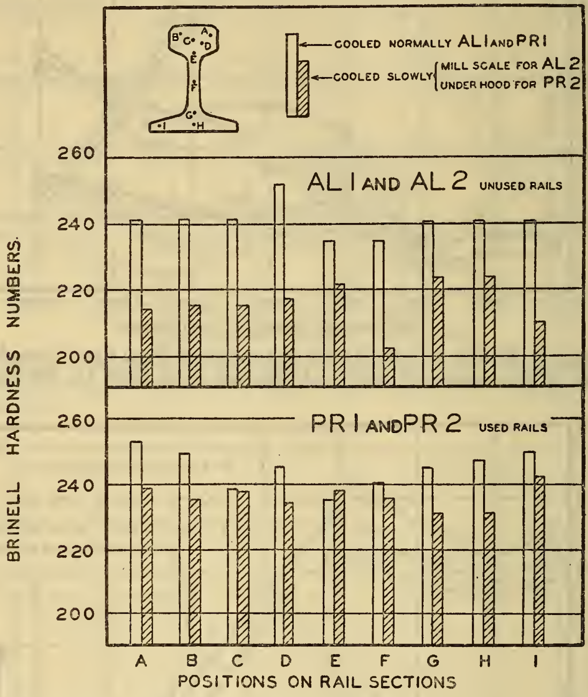

Figure 9.—*Results of Brinell hardness tests on rails AL1, AL2, PR1, and PR2*

As might be expected, the hardness at room temperature was reduced by slow cooling. The results of Brinell tests on rails AL1, AL2, PR1, and PR2 at the various positions indicated are shown in Figure 9, and Figure 10 gives the hardness results on some of the S rails. The results show that the rails cooled slowly were softer over the section than those cooled normally, and that the standard rails after "interrupted cooling" were intermediate in hardness. The results for medium manganese rails subjected to this interrupted cooling were less consistent and for most of the positions were as hard or harder than the corresponding positions on the rail cooled normally.

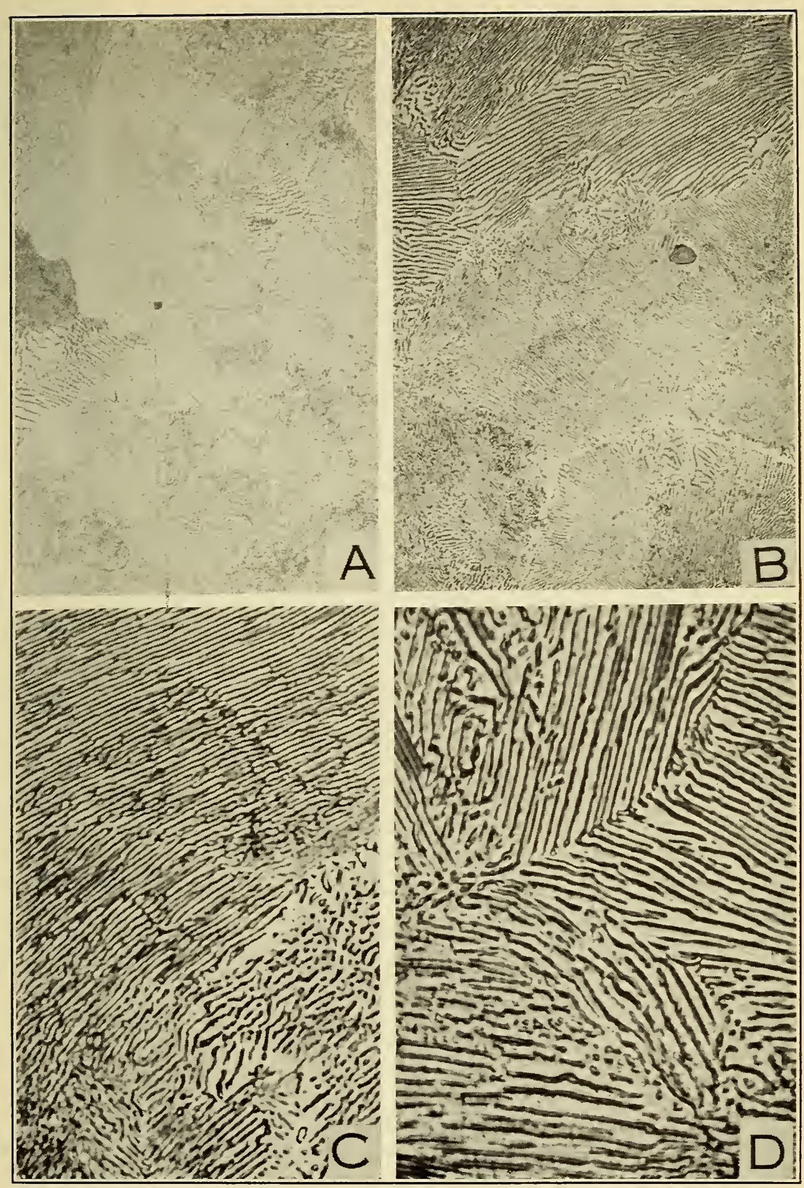

Figure 7.—*Structure of new "standard" rails AL1 cooled normally and AL2 cooled slowly from the hot saw in mill scale*

A, AL1, × 500; *B*, AL2, × 500; *C*, AL1, × 2,000; *D*, AL2, × 2,000. Etchant, 2 per cent nitric acid in alcohol.

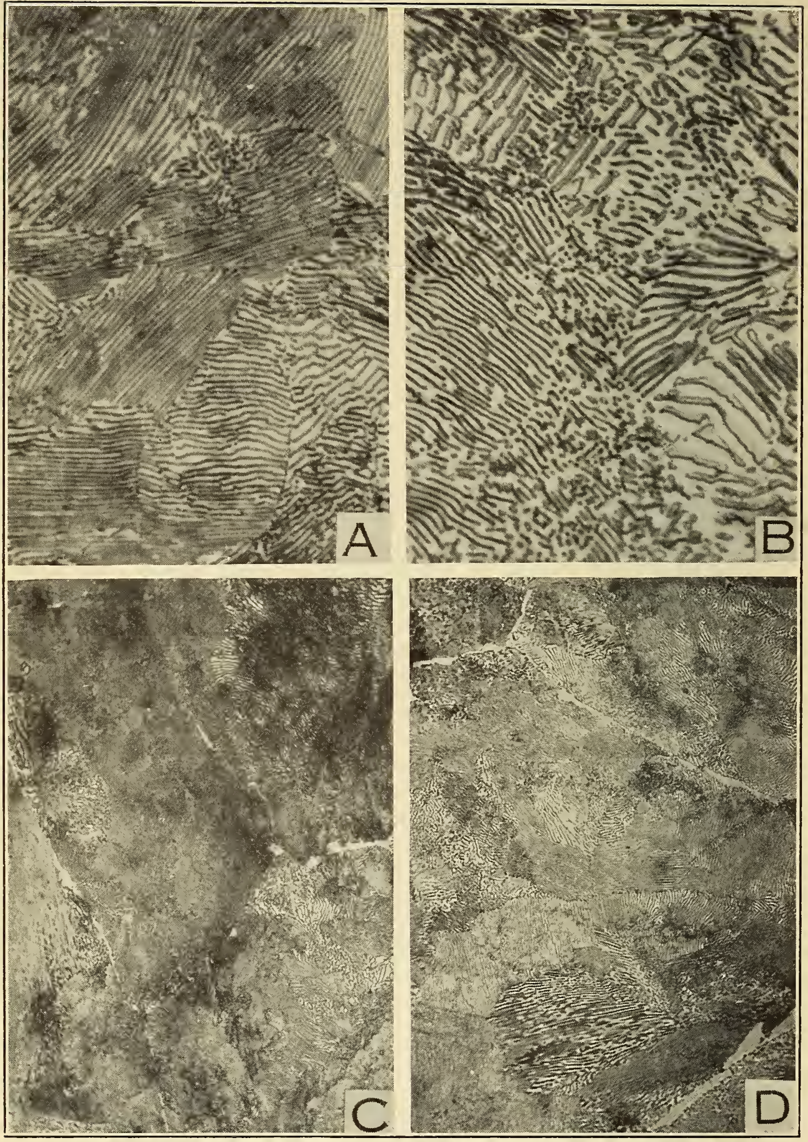

Figure 8.—*Structure of rails*

A, "Standard" PR1 cooled normally, × 2,000; *B* "Standard" PR2 cooled slowly from hot saw under a hood, × 2,000; *C*, S6 medium manganese cooled normally, × 500; and *D*, S4 medium manganese cooled slowly from hot saw in mill scale, × 500. Etchant, 2 per cent nitric acid in alcohol.

2. FISSURED *v.* UNFISSURED RAILS

Two pieces of medium manganese rail of 130-pound section, which had served in track for the same length of time, were obtained through the courtesy of the Delaware, Lackawanna & Western Railroad. Transverse fissures had been detected in the rail designated DL1, whereas no fissures had been detected in the rail designated DL2. Elevated-temperature tensile tests were made on both of these rails to ascertain if these differences in service behavior were accompanied by differences in the properties. From the results shown in Figure 11, it is evident that there were no appreciable differences in the tensile properties. Similar tests were made on two 90-pound rails, from the Canadian Pacific Railroad (CP1 and CP2), in one of which a transverse fissure had been detected whereas in the other no fissures were detected. The results are shown in Figure 12, and it is seen that there was only a small difference in the properties and that CP2, the fissured rail, showed slightly greater secondary brittleness.

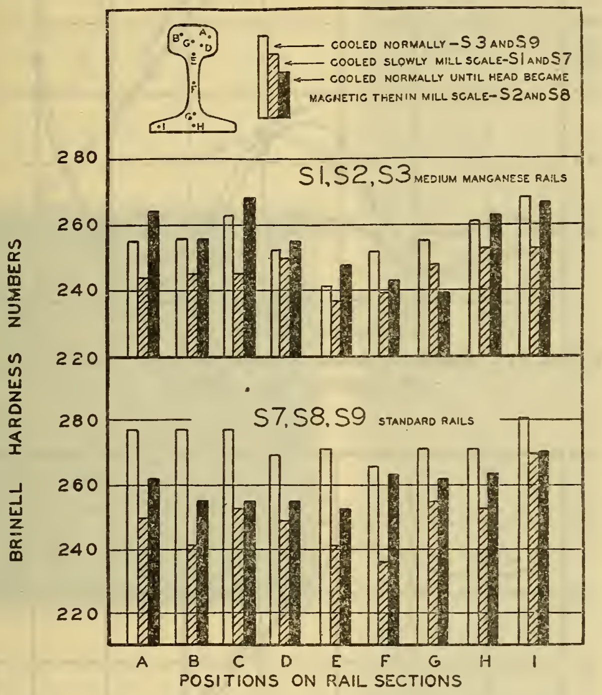

FIGURE 10.—*Results of Brinell hardness tests on rails S1, S2, and S3 medium manganese and S7, S8, and S9 "standard" rails*

An examination of longitudinal deep-etched sections of rail DL1 (transverse fissured) revealed three longitudinal cracks, whereas the unfissured rail, DL2, when etched, revealed no cracks. Figure 13 shows a crack at natural size and at 20 magnifications. It is seen that the defect is an irregular crack with a general longitudinal direction. Similarly, shatter cracks were found in rail CP1 (fissured), but no cracks were found in rail CP2 (not fissured).

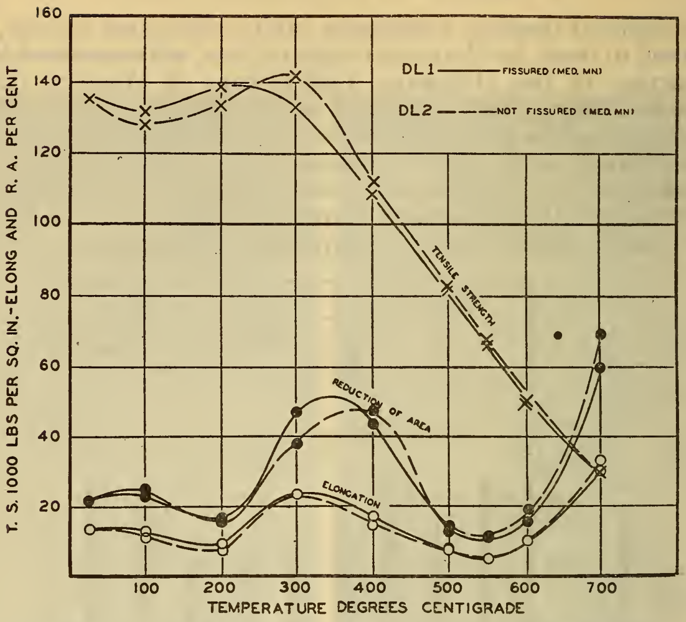

FIGURE 11.—*Results of tensile tests on medium manganese rails*
DL1, fissured; DL2, not fissured.

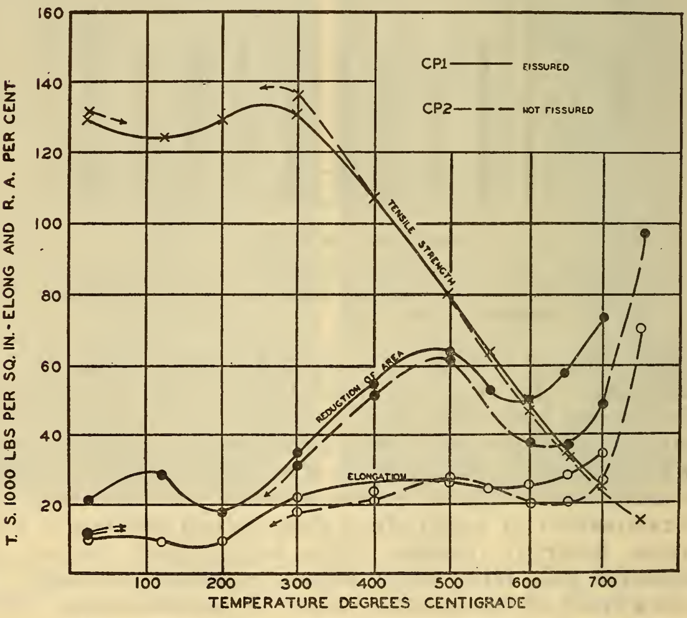

FIGURE 12.—*Results of tensile tests on "standard" rails*
CP1, fissured; CP2, not fissured.

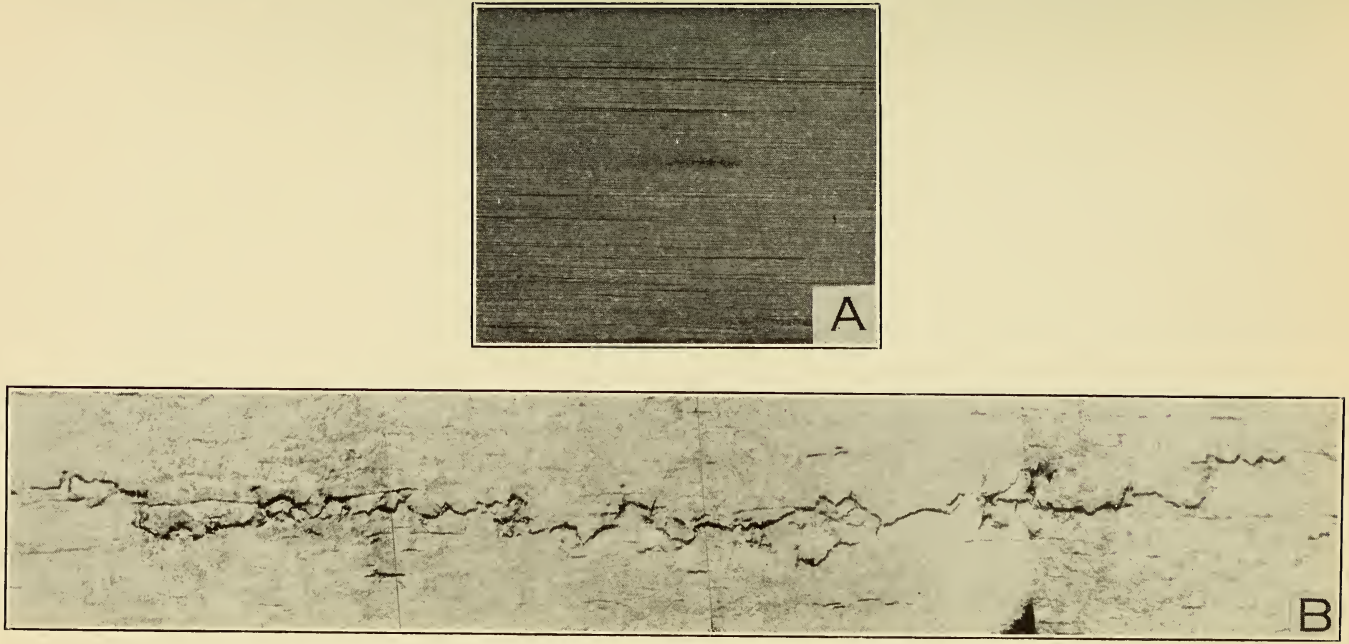

Figure 13.—*Crack in medium manganese rail DL1, fissured*

A, × 1; *B*, × 20.

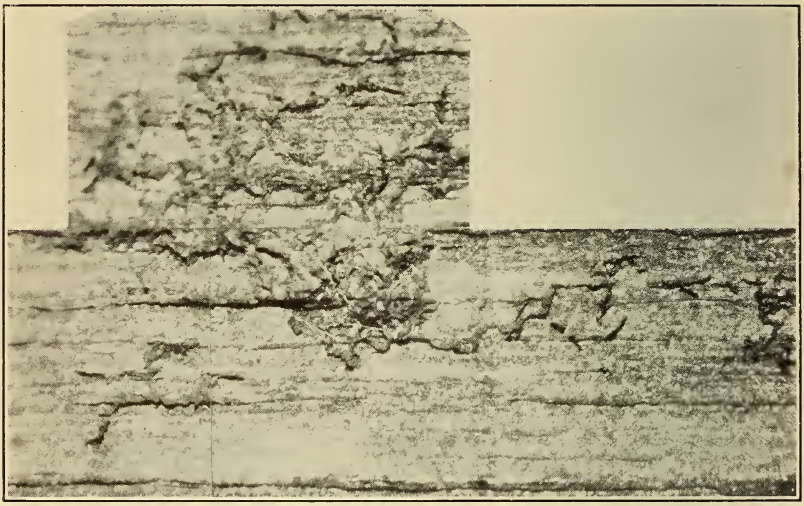

FIGURE 14.—*Shattered area in used rail LN1.* × 35

Figure 15.—*Longitudinal horizontal section three-fourths inch below the tread of used rail LN3.* × *1 showing shatter cracks*

Figure 16.—*Longitudinal horizontal section three-fourths inch below the tread of used rail NC.* × *1 showing shatter cracks*

3. RAILS FROM SAME MILL ROLLED AT DIFFERENT PERIODS

Statistics[4] on transverse fissure show that the total accumulated number of transverse fissures per year has been increasing gradually and uniformly. There have been greater numbers of failures in rails rolled in certain years, particularly 1917, 1923, 1925, 1926, and 1927 than in other years. The greater number of failures in 1925, 1926, and 1927 were attributed principally to the excessive rate of failure in the output of a particular mill for those years. Fissure failures reported by the American Railway Engineering Association during the last few years as occurring in the first year of service are given in Table 2.

TABLE 2.—*Fissure failures occurring in first year of service*

29 failures in 1925 from 1925 rollings, all mills.
50 failures in 1926 from 1926 rollings, all mills.
114 failures in 1927 from 1927 rollings, all mills.
58 failures in 1928 from 1928 rollings, all mills.
106 failures in 1929 from 1929 rollings, all mills.

The improvement in the 1928 rollings shown above, according to Mr. Barnes' report, is due to the fact that only 3 out of a total of 58 failures were from this one mill, while in the first year of service of 1927 they produced 56 out of a total of 114 failures. This marked improvement in their rails from the fissure standpoint appears to be the result of changes in practice which were put into effect starting with July, 1927. Table 3 shows this more clearly.

TABLE 3.—*Fissure failures in rails from a particular mill (all roads) showing improvement attributable to changes in mill practice*

Year of failures	When rolled (year, months)				
	1925, January-December	1926, January-December	1927, January-June	1927, July-December	1928, January-December
1928	123	140	56	0	----------
1929	131	210	160	3	3
Total	254	350	216	3	3

Through the cooperation of Mr. Barnes, rails made at this mill were secured before and after July, 1927, as given in Table 4.

TABLE 4.—*Rails tested from a particular mill*

Railroad	Designation	Year rolled	Heat No.	Remarks
Louisville & Nashville.	LN1	January, 1927	874163	
	LN2	January, 1928	815420	
	LN3	December, 1928	885445	Failed from transverse fissure; 100-pound "C" rail.
Missouri Pacific	MP1	1926	856284	85-pound "A" rail.
	MP2	1929	829732	90-pound "G" rail.
Nashville & Chattanooga.	NC	December, 1924	42249	Failed from transverse fissure; 90-pound "C" rail.

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[4] R. E. Barnes, Engr. of Tests, Rail Com., A. R. E. A., Transverse Fissure Statistics, A. R. E. A., vol. 31; p. 1485; 1930, vol. 32, p. 365; 1931.

Of the rails shown in Table 4, rails LN3 and NC had failed from a transverse fissure. Longitudinal sections of each of the six rails were deep etched. A small shattered area was found in rails LN1 and LN3, but in rail LN2 no shatter was found. These isolated observations check the service results in Table 3 which shows that rails rolled shortly after July, 1927, were better than those rolled previously or subsequently. Figure 14 shows the shattered area in the LN1 section and an etched longitudinal section of LN3 is shown in Figure 15. In this figure are seen a number of transverse and longitudinal cracks.

No shatter cracks were found in deep-etched sections of either MP1 or MP2. Many streaks were revealed in MP1 ("A" rail) while in MP2 ("G" rail) this condition was absent. A number of transverse and longitudinal cracks shown in Figure 16 were found in a deep-etched section from rail NC which was a 90-pound "C" rail, rolled at this mill in 1924. This section was taken longitudinally five-eighths inch below the tread. The rail, which had a transverse fissure on the end, was from a heat of which five rails broke between January 28 and March 9, 1925.

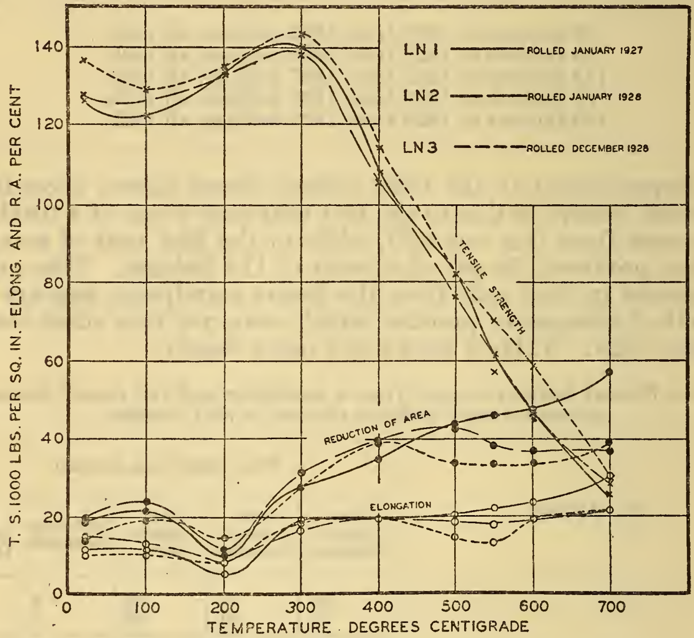

Figure 17.—*Results of tensile tests of specimens from used rails LN1, LN2, and LN3*

Elevated-temperature tensile tests were made on specimens from all of these rails and the results are given in Figures 17, 18, and 19. Although these specimens did not have a marked decrease in ductility in the secondary brittle range the values were generally somewhat lower from 400° to 700° C. than given for other rails in this or the previous publication. As shown in Figure 17 there were differences in ductility of these rails between 400° and 700° C. and the ductility curves of LN2 which revealed no cracks on deep etching lie between

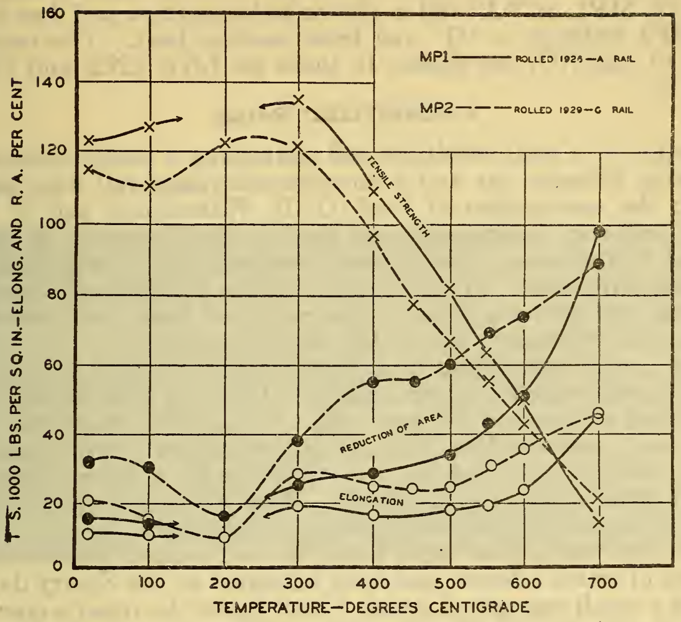

Figure 18.—*Results of tensile tests of specimens from used rails MP1 and MP2*

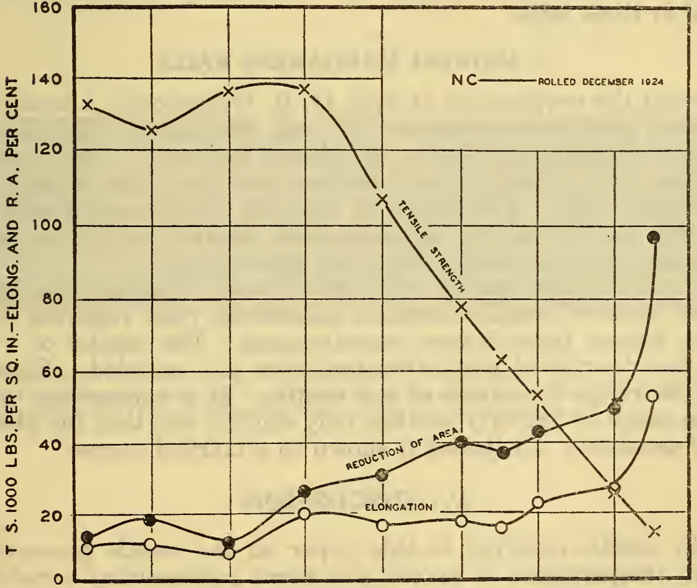

Figure 19.—*Results of tensile tests of specimens from used rail NC*

those of LN1 and LN3 which were presumably inferior rails. In Figure 18, MP1, an "A" rail is shown to be stronger and less ductile than MP2 which is a "G" rail from another heat. The curves in Figure 19, rail NC, are similar to those for LN1, LN2, and LN3 in Figure 17.

4. SORBITIZED RAILS

A section of a used sorbitized rail containing a fissure detected by the Sperry detector car and a corresponding new rail were secured through the cooperation of Prof. G. B. Waterhouse and of H. S. Clarke, engineer, maintenance of way of the Delaware & Hudson Railroad Corporation. Both were 90-pound "C" rails, but were from different heats. The used rail was from the fifth and the unused one from the eleventh ingot. The rails had been heat treated by a commercial process to render the structure sorbitic.

Many cracks were found in a deep-etched section of the new rail, DH1, but relatively few in the used rail, DH2. Figure 20 shows two longitudinal sections of the new rail. It has been suggested previously [5] that rapid cooling through the secondary brittle range is a cause of shatter cracks and the cracks found in the more rapidly cooled new rail gives weight to this theory. The left end of the horizontal section of Figure 20 is the hot sawed end of the rail.

Relatively few cracks were found in two etched sections of the DH2 rail in which a fissure had been indicated by the Sperry detector car. In a small segregated streak 1 inch below the tread a crack was observed with the aid of a hand glass. Figure 21 shows the crack and the structure of both the segregated streak and the area adjacent to it. The results of tensile tests at elevated temperatures on these two rails are shown in Figure 22. Secondary brittleness is very marked in these rails.

5. MEDIUM MANGANESE RAILS

Through the cooperation of Prof. G. B. Waterhouse, a section of a 130-pound medium manganese "F" rail designated "K," Table 1, was secured from the Boston & Maine Railroad. The steel was deoxidized with zirconium and the rail was from the seventh ingot of a 14-ingot heat. The results of elevated temperature tensile tests are shown in Figure 23. The material showed marked secondary brittleness similar to many other rails tested.

The curves from tensile tests at elevated temperatures on six different heats of regular medium manganese rails, reported in this and the former paper [5] were superimposed. The results on rail K which was deoxidized with zirconium were not included. Figure 24 shows the range or scatter of the results. It is interesting to note that the range of ductility scatters only slightly and that the phenomenon of secondary brittleness is shown to a marked degree.

IV. DISCUSSION

In the results reported in this paper on the tensile properties at elevated temperatures of several rail steels representing variables in manufacture and composition of rails, it is interesting to note the effect of these variables on the quality, structure, and the properties

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[5] See footnote 2, p. 174.

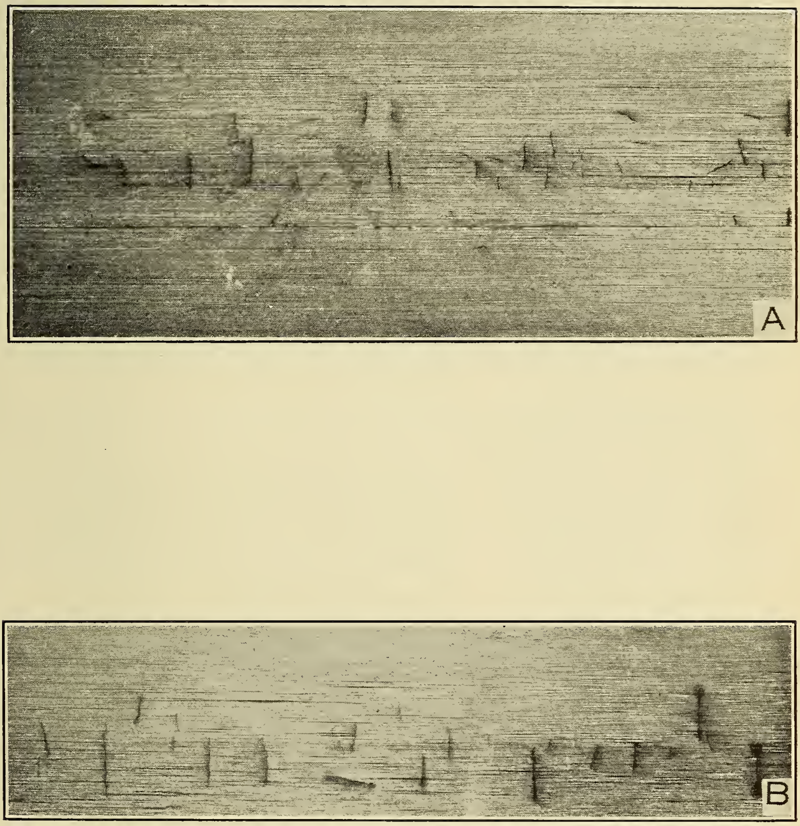

Figure 20.—*Sections of new sorbitized rail DH1.* × ⅔

A, Longitudinal horizontal section three-fourths inch below the tread. The left is the hot sawed end; *B*, longitudinal vertical section through the center of the head. The tread is at the top of the photographs. This section is some distance from the hot sawed end.

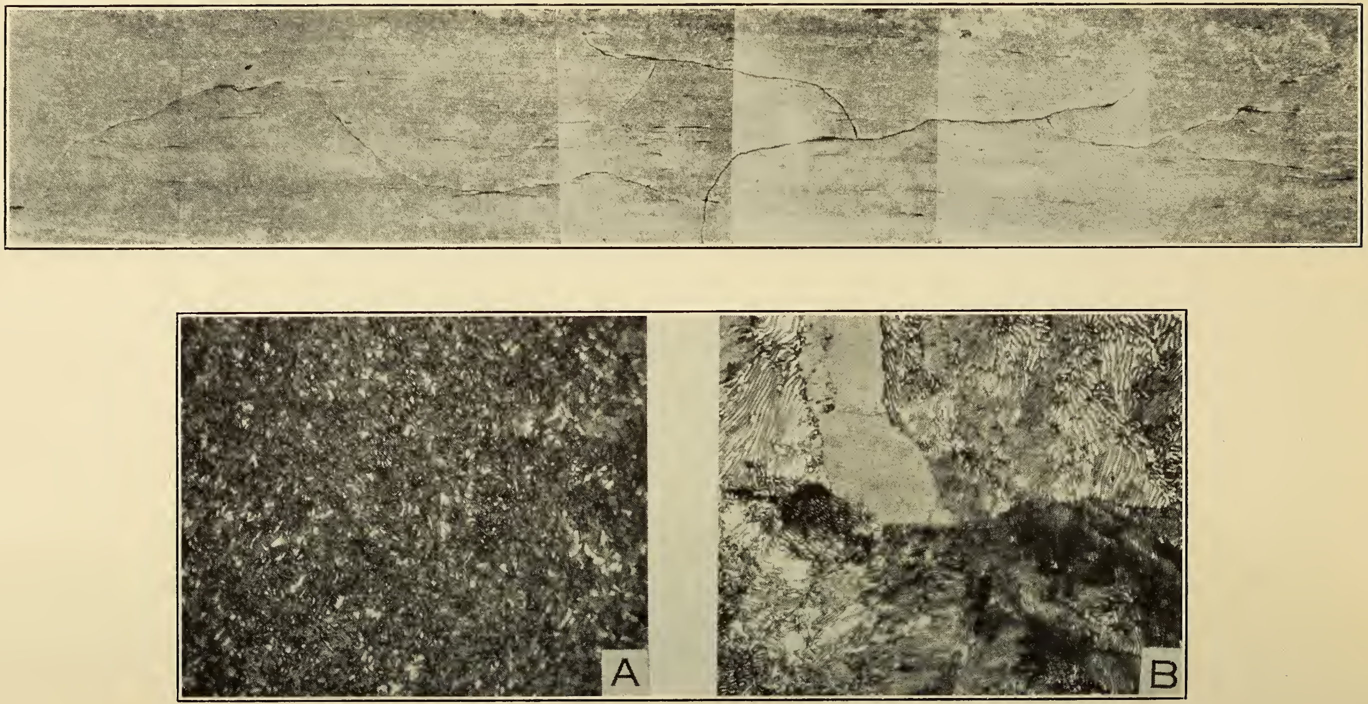

Figure 21.—*Crack in a segregated spot in used sorbitized rail DH2, 1 inch below the tread.* × *20*

A, Structure of segregated area (× 1,200); *B*, structure of the rail just off the segregated area (× 1,200).

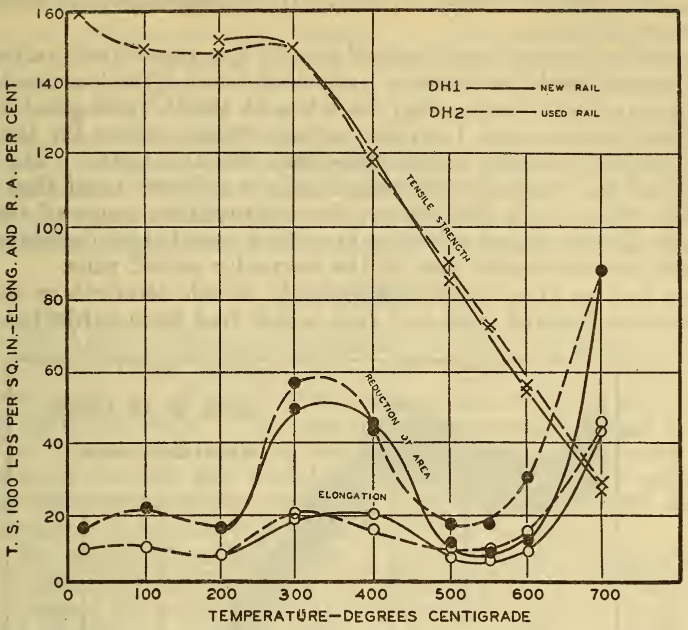

FIGURE 22.—*Results of tensile tests on specimens from sorbitized rails* DH1, new rail; DH2, used rail.

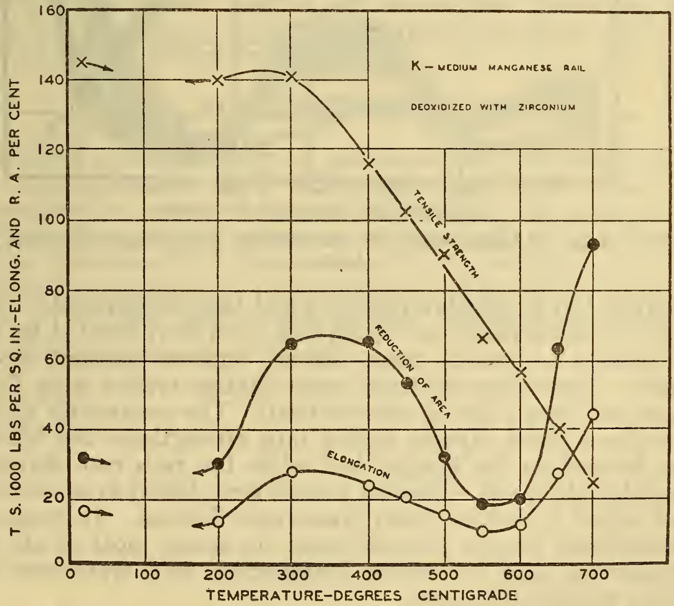

FIGURE 23.—*Results of tensile tests on specimens from a medium manganese rail deoxidized with zirconium*

in the temperature range in which the phenomenon of secondary brittleness occurs.

The elongation and reduction of area of specimens from rails cooled slowly in mill scale or under a preheated hood after leaving the hot saw fluctuate less; that is, they were less at 400° C. and greater in the secondary brittle range than the corresponding values for the specimens from the normally cooled rails from the same heats. The tensile strength of the more slowly cooled rails was lower than that of the normally cooled rails throughout the temperature range of test. In the more slowly cooled rails the structure was better developed and the peralite was coarser than in the normally cooled rails.

There was no appreciable difference in tensile strength or ductility of transverse fissured rails and rails which had been subjected to the same service, but in which no fissures had been discovered. Tests on a used and on an unused rail which had been heat treated by a commercial process to render them sorbitic showed marked secondary brittleness. Upon deep etching many shatter cracks were found in the unused rail and a few in the used rail. The prevalence of shatter cracks in these more rapidly cooled rails strengthens the belief that they are formed on the cooling bed while the rails cool through the secondary brittle range. Shatter cracks were found in all of the rails that had failed in service from transverse fissures. In some of the rails longitudinal cracks predominated; in some, most of the cracks were transverse; and in others, longitudinal and transverse cracks were about equally prevalent.

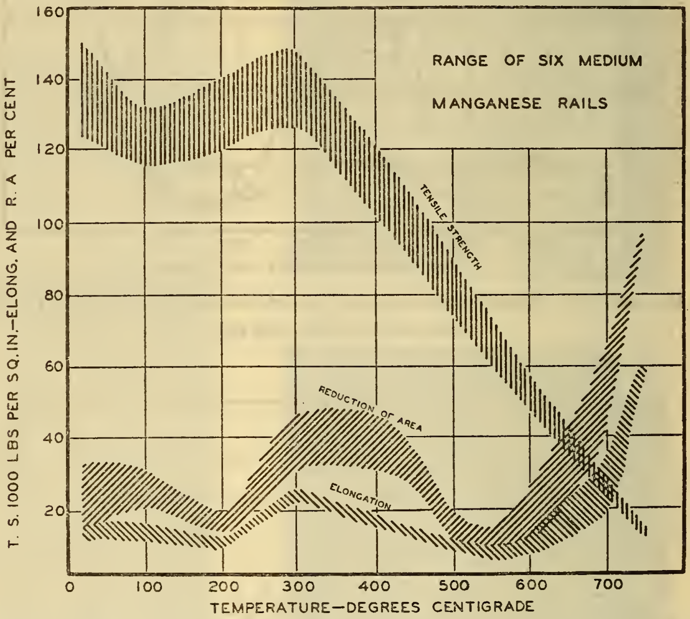

Figure 24.—*Range of tensile results on six medium manganese rails from different heats*

Marked secondary brittleness was observed in all of the medium manganese rails tested, including one from a heat which had been deoxidized with zirconium. A composite figure of the results of elevated temperature tests on specimens from six different heats of medium manganese rail steel reported in this paper and previously showed very little scatter in the secondary brittle range. The results of elevated temperature tests on specimens of rails which were rolled at a particular mill and in which many failures resulted subsequently in service from transverse fissures, and on specimens which were rolled at a subsequent period when the rails were improved showed little decrease in ductility in the secondary brittle range, but the ductility values at certain temperatures, particularly at 400° and 700° C., were lower than those of other rails given in this and the previous paper.

V. SUMMARY

In continuation of the work published in 1930 [6] on Tensile Properties of Rail and Other Steels at Elevated Temperatures, tensile tests have been made at elevated temperatures on 28 specimens of rails from 18 different heats. The material represented different rates of cooling on the hot bed for both carbon and medium manganese rails; samples from fissured and unfissured rails; rails from the same mill rolled at different periods; sorbitized rails, both used and unused; and a medium manganese rail deoxidized with zirconium.

From the results given in this and a previous paper, the indications are that secondary brittleness is an inherent property in the steels used at present for rails, but that the ductility may be appreciably improved by slow cooling through the temperature range in which this phenomenon occurrs.

Inasmuch as shatter cracks have been found in all transverse fissured rails and occasionally in new rails, it is believed that they are the nuclei of transverse fissures. It seems that transverse fissures would be less frequent in slowly cooled rails because of the increased ductility in the secondary brittle range.

VI. ACKNOWLEDGMENTS

The author takes pleasure in acknowledging the effective cooperation of R. E. Barnes, G. B. Waterhouse, and O. W. Ellis through whose cooperation much of the material tested was secured. He is also indebted to several members of the staff of the Bureau of Standards, including H. S. Rawdon and W. H. Swanger, for valuable suggestions throughout the investigation and to K. A. Milliken for carefully performing most of the elevated temperature tensile tests.

WASHINGTON, November 28, 1931.

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[6] See footnote 2, p. 174.