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INTERSTATE COMMERCE COMMISSION

REPORT OF THE DIRECTOR OF THE BUREAU OF SAFETY IN RE INVESTIGATION OF AN ACCIDENT WHICH OCCURRED ON THE ST. LOUIS–SAN FRANCISCO RAILWAY NEAR VICTORIA, MISS., ON OCTOBER 27, 1925[1]

June 16, 1927

To the Commission:

On October 27, 1925, there was a derailment of a passenger train on the St. Louis-San Francisco Railway near Victoria, Miss., which resulted in the death of 20 passengers and 1 employee of the railroad and the injury of 117 passengers, 8 Pullman employees, 3 mail clerks, and 2 employees of the railroad. The investigation of this accident was made in conjunction with a representative of the Mississippi Railroad Commission.

LOCATION AND METHOD OF OPERATION

This accident occurred on the Tupelo subdivision of the southern division, extending between Memphis, Tenn., and Amory, Miss., a distance of 126.8 miles. This was a single-track line over which trains were operated by time-table and train orders, no block-signal system being in use. The point of accident was 1,351 feet south of the station at Victoria; approaching this point from the south the track was tangent a distance of 2,387 feet, with a descending grade for northbound trains of 1 per cent.

The track was laid with 90-pound rails 33 feet in length, with an average of 20 treated red-oak ties to the rail length, tie plated and single spiked, and ballasted with about 12 inches of slag. The general maintenance of the track was good. At the point of accident the track was on a fill about 11 feet in height, while 506 feet north of the point of accident there was an eight-panel pile trestle.

The weather was clear at the time of the accident, which occurred between 6.35 and 6.40 a. m.

[1] Preparation of report delayed on account of large amount of research work occasioned in obtaining the necessary data.

DESCRIPTION

Northbound passenger train No 108 consisted of 1 refrigerator express car, 1 combination mail and baggage car, 1 baggage car, 2 coaches, and 7 Pullman sleeping cars, hauled by engine 1060, and was in charge of Conductor Ryan and Engineman Herring The fifth car was of wooden construction, the first, second, third, and tenth cars were of steel-underframe construction, and the others were of all-steel construction This train left Holly Springs, 12 4 miles south of Victoria, at 6 20 a m, five minutes late and was approaching Victoria when it was derailed while traveling at a speed estimated to have been between 40 and 50 miles per hour

The engine and tender were not derailed, but broke away from the cars and finally were brought to a stop at a point 2,118 feet north of the initial point of accident The first 10 cars and the forward truck of the eleventh car were derailed, all the derailed equipment going to the left of the track The first car passed over the trestle and came to rest on its left side about 735 feet north of the initial point of accident, and the next two cars were bottom up opposite the trestle The fourth and fifth cars came to rest on their right sides, with the sixth car on its left side, while the next four cars remained nearly upright, leaning toward the left The employee killed was the conductor

SUMMARY OF EVIDENCE

Engineman Herring estimated that his train was approaching Victoria at a speed of 45 or 50 miles per hour when he felt the air brakes apply as if a hose had parted He had not noticed any jar which might have resulted from passing over a broken rail and he said that he did not make any investigation for the purpose of ascertaining the cause of the accident The statements of Fireman Young brought out nothing additional of importance Flagman Fleming went back to protect his train and he also stated that he did not make any investigation into the cause of the accident

The engine and train crews of northbound extra 4012, the last train to pass over this section of track prior to the occurrence of the accident, said that at that time they did not notice anything wrong with the track

Examination of the track developed the fact that the first mark of derailment was at the point where a rail had broken on the left or west side of the track The initial fracture was located 13 feet 8¾ inches from the receiving end of the rail and the surfaces of the fracture showed the presence of a well-defined transverse fissure on the gauge side of the head of the rail This fracture at one point extended to within one thirty-second of an inch of the surface of the rail, and its appearance indicated that air had reached it, the metal having been oxidized; north of this initial fracture the rail was broken into several pieces. The examination of the track did not indicate that there was anything else wrong with it, nor was there any evidence of dragging equipment, while careful examination of the engine failed to disclose anything wrong. The coupler had pulled out of the head end of the first car. Engineman Herring said this coupler was lying on the track near the switch opposite where the first car came to rest, and it is not considered that the pulling out of this coupler had anything to do with the accident.

This accident was caused by a broken rail, the examination of which was made by Mr. James E. Howard, engineer-physicist, whose report follows. It was the most serious one due to a transverse fissure which has occurred since the accident at Manchester, N. Y., on the Lehigh Valley Railroad on August 25, 1911, when this type of fracture was first brought to general notice in a report of the Interstate Commerce Commission.

A transverse fissure is recognized as the most dangerous type of fracture encountered in railroad service. Transverse fissures are appearing in the track in numbers which are very disquieting. The physical reasons for their display seem explainable. Means for their prevention under current traffic have not been found.

The engineer-physicist has added to the report upon the rail which was the cause of the present accident remarks upon physical properties inherent to different steels, in review of the general subject of transverse fissures, extending the remarks to other types of rail fractures. The conditions which tend to cause the display of transverse fissures are present in all rails. The specific reasons for their occurrence are more clearly presented in this comprehensive review.

Respectfully, W. P. BORLAND, *Director*.

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REPORT OF THE ENGINEER-PHYSICIST

The derailment of passenger train No 108, near Victoria, Miss, on October 27, 1925, was caused by a broken rail which displayed a transverse fissure at its initial point of rupture This fracture was located 13 feet $8\frac{3}{4}$ inches from the receiving end of the rail From this point to the leaving end the rail was broken into not less that nine pieces Four additional partially developed transverse fissures were displayed by these fragments

The broken rail was located on the left side of the track, with reference to the direction the train was traveling The rails from both sides of the track were torn up for a distance of about 340 feet Beyond the opening thus made the track was not seriously damaged

The circumstances attending the derailment were doubtless as follows The initial fracture of the broken rail probably occurred under the wheels of the engine The track structure remained serviceable for a short time, allowing the engine, tender, and three cars of the train to pass over it in safety The leaving end of the rail soon began to break up and was successively broken into short fragments Through this opening the middle part of the train was derailed and the track structure then destroyed for a distance of 340 feet

The engine and tender kept on the rails, in advance of the destroyed section, and came to rest at a distance of 2,118 feet beyond the initial break The last car of the train came to rest before it reached the place occupied by the broken rail Cars of the forward end of the train were dragged over the westerly side of the track The fifth car a day coach, and the sixth car, a Pullman sleeper, were jammed together, each being badly damaged Four of the rear Pullman sleepers were partially overturned, while two remained upright on the track

Figure No. 1 is a plan of the track taken from a blue print from the office of the division engineer of the railroad. It shows the first car of the train on its side, the second and third cars bottom side up, the fourth car on its side, the fifth and sixth cars, a day coach and a Pullman sleeper, jammed together. Four Pullman sleepers, next in order, leaned outward at different angles, while the last two Pullman sleepers remained in upright positions. The car next the last one of the train spanned the broken rail, its forward truck derailed, its rear truck on the rails.

The rails from the west side of the track were broken or detached from each other. Nine rails of the east side of the track remained attached to each other, their splice bars unbroken. These nine rails were ploughed off the ties and thrown from the roadbed out on to the highway paralleling the track. They formed a large loop which extended at its farthest point 75 feet from their position in the track. They were bent sidewise, some convex on the gauge side, others concave. Figure No. 2 illustrates the positions occupied by these nine rails after the accident. They were thrown from the track with such force and suddenness that the loop was made in the air and fell almost vertically upon the highway.

Figure No. 3 is a view of the first Pullman sleeper, the Jitonmi, showing the manner in which the middle part of its length crushed the rear end of the day coach.

Figure No. 4 shows the derailed Pullman sleepers, Sebago, Red Granite, Argonne, and Jitonmi, respectively.

Figure No. 5 is a drawing of the rail which broke and caused the accident. It weighed 90 pounds per yard, was rolled by the Tennessee Coal, Iron & Railroad Company in the month of October, 1918, and was laid in the track in April, 1919. It had been in service, therefore, 6 years and 6 months. It was branded O. H. Tennessee A. S. C. E. 9040 10 1918. Heat number 17054, ingot letter C.

There was a transverse fissure at the first break in the rail which measured 1 13/16 by 1 7/16 inches. The surfaces were darkened, indicating the fissure had reached the periphery of the head and air had been admitted prior to the accident.

For convenience of reference the fragments of this rail are designated by letters of the alphabet. The first break was between fragments A and B, which displayed the transverse fissure above described. Four additional transverse fissures were displayed at the time of the accident, the positions of which are indicated by Figure No. 5. Each of these showed bright surfaces with a silvery luster. None of these four had reached the surface of the head prior to the accident. Subsequently a hammer test of fragment A revealed two more transverse fissures, making in all seven in this rail.

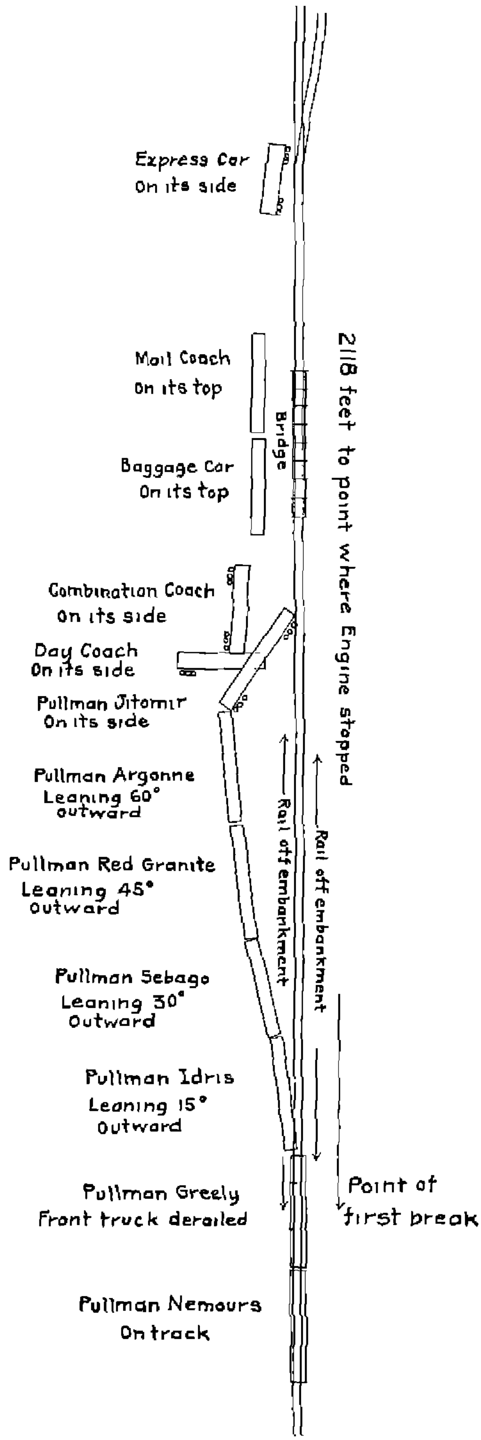

Fig 1.—Plan of the track showing positions occupied by the derailed cars

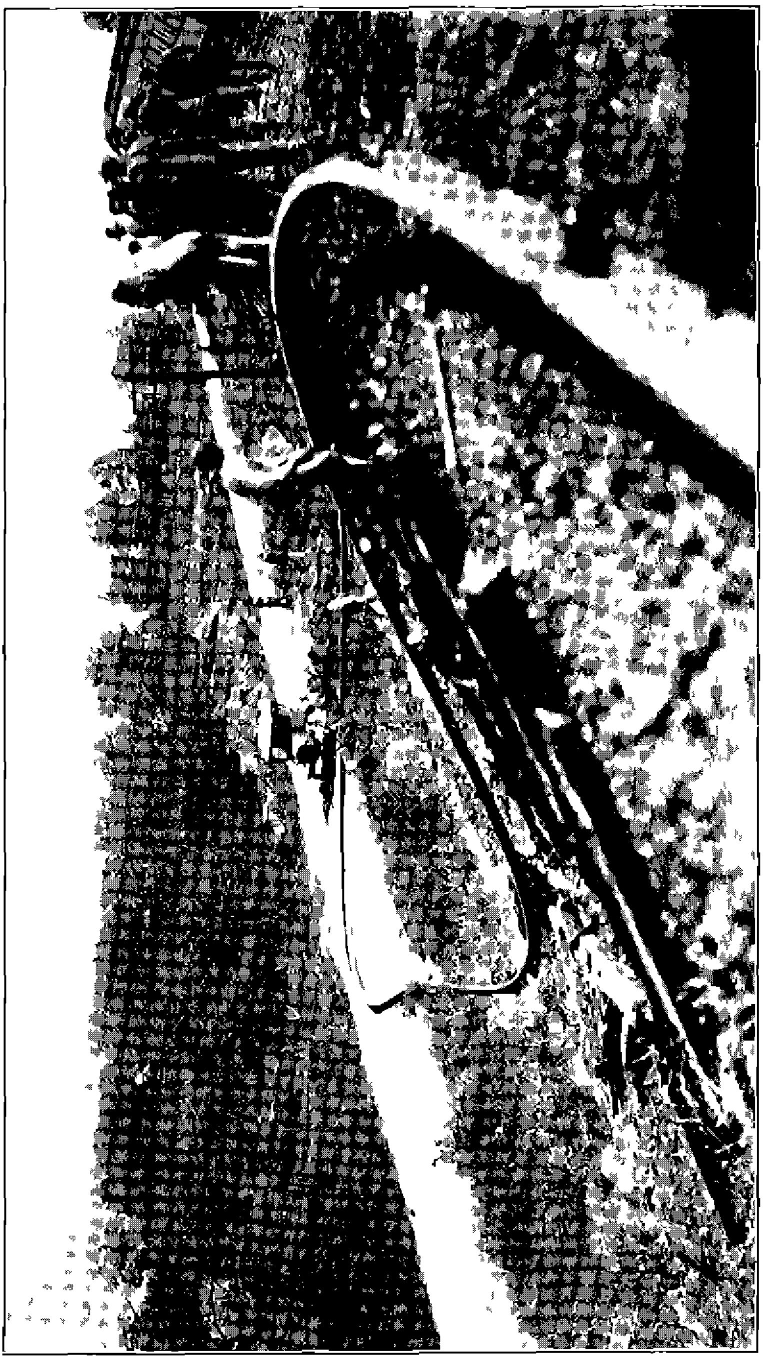

FIG. 2.—Loop made by nine rails plowed off the easterly side of the track. Rail, bent splice bars unbroken

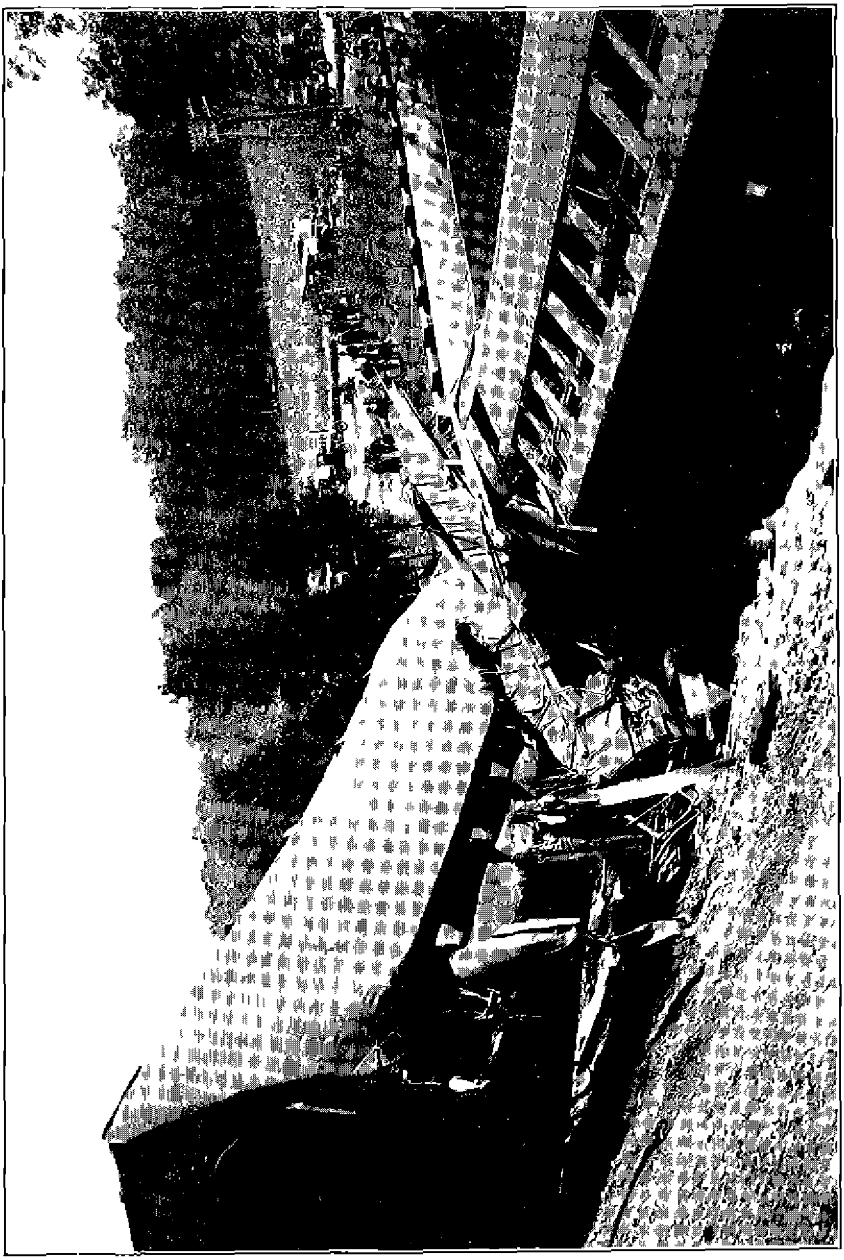

FIG 3.—View of the Pullman sleeper the Jitomar and a day coach. Middle of Pullman sleeper and end of day coach jammed together

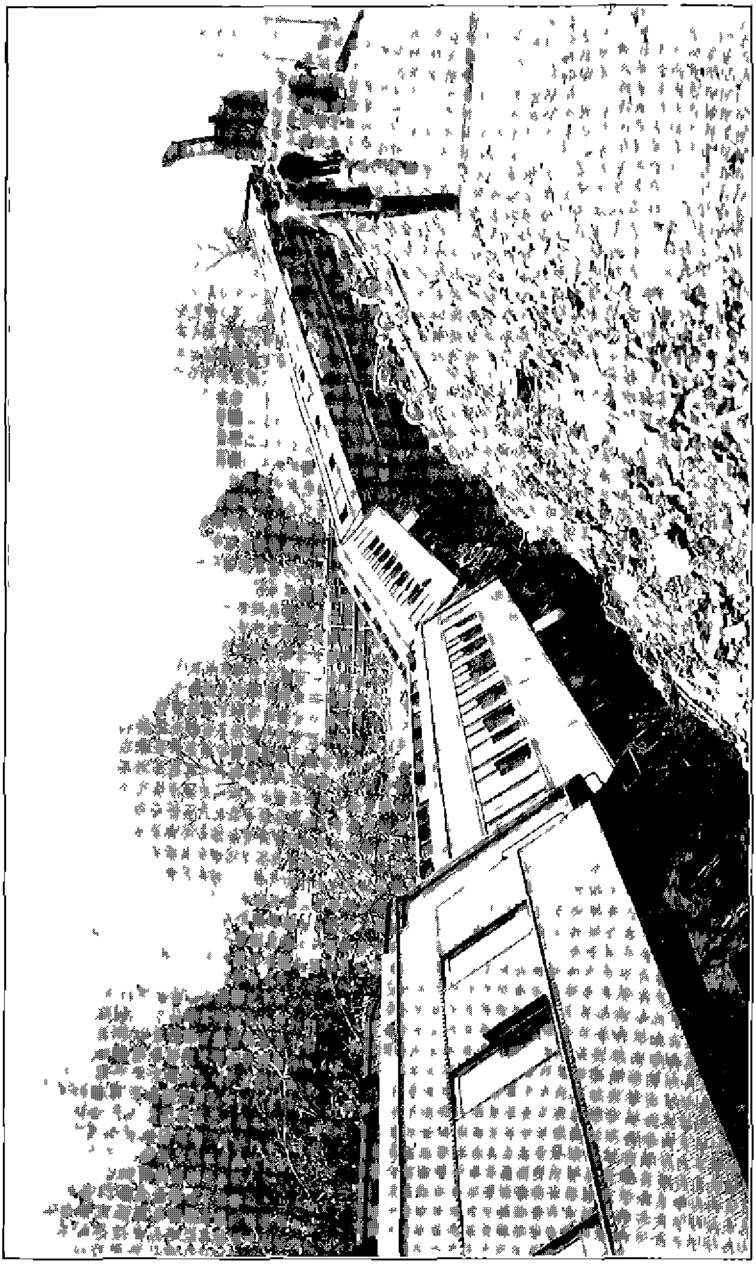

FIG. 4—View of the derailed Pullman sleepers Sebago, Red Granite, Argonne and Altoona respectively

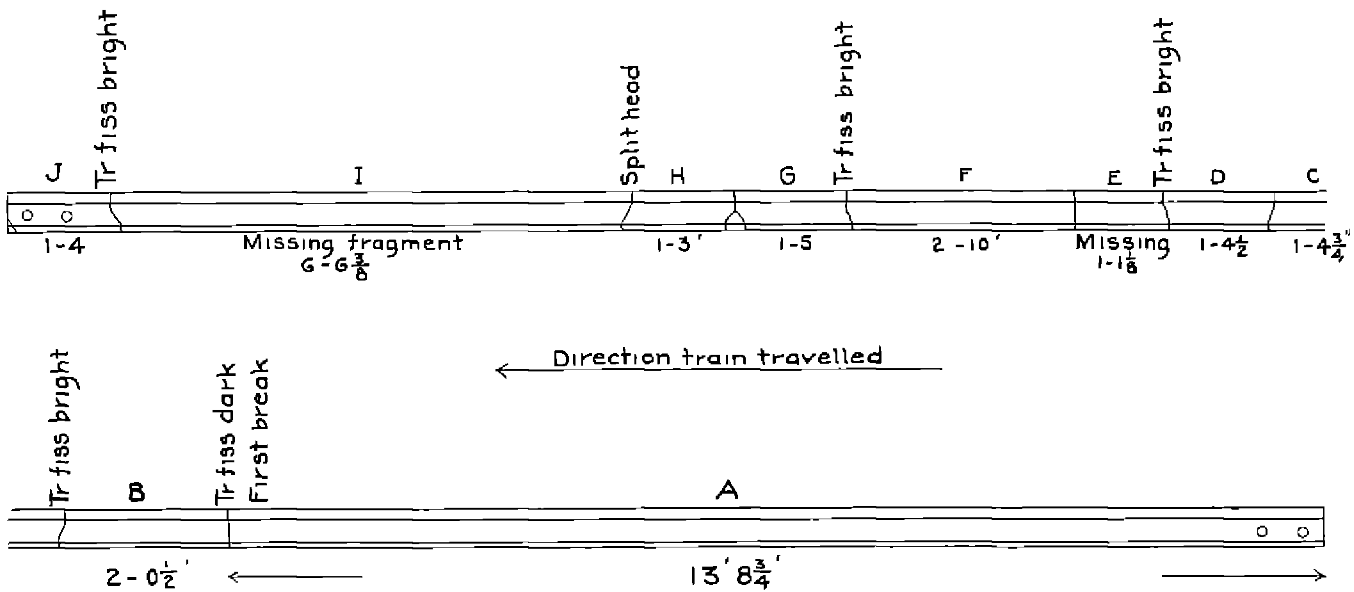

FIG 5—Drawing of the rail which caused the accident, showing location of fractures made in the track. Rail branded O H Tenn A S C F 9040 10 1918. Heat number and ingot letter 17054C

Figure No 6 illustrates the appearance of the opposite faces of the transverse fissure at the first break in the rail The section on the left of the cut represents the leaving end of fragment A, the section on the right, the receiving end of fragment B This transverse fissure covered more than one-half the cross section of the area of the head The nucleus of the fissure was located on the gauge side of the head, not quite half way down its depth

Figure No 7 shows the appearance of one of the additional transverse fissures found in fragment A under the hammer test Its bright silvery luster will be noted, a characteristic feature of transverse fissures before air is admitted to them Its nucleus is on the gauge side of the head, in common with all others of this rail

The manner of conducting the hammer tests was to place the rail, head down, on supports at the edges of the anvil and strike the rail on the base midway the supports, repeating the blows at short intervals along its length Continuing the hammer tests, other rails were examined which came from the destroyed section of the track Eleven rails were tested, five of which had the same heat number as the rail which first broke but different ingot letters Six had different heat numbers but were of the same year's rolling, that is, 1918 Two short pieces of curve worn rails were included in this examination which were not involved in the derailment They had been used in rerailing the cars

One of the objects of the hammer tests was to ascertain the condition of rails in the vicinity of the accident, whether transverse fissures were generally prevalent in that locality One other rail, besides the rail first to break, displayed a transverse fissure in the track In this rail three additional fissures were found, which measured one-fourth, three-sixteenth and seven-sixteenth inch diameters, respectively This rail had the same heat number as the rail which first broke, but with the ingot letter F None of the other rails displayed transverse fissures

Two pieces of the curve worn rail were tested Five fractures were made with the first piece, each brittle fractures and each starting at the corner of the head, gauge side The second piece was annealed before testing Its toughness was restored, resisting the hammer blows without rupture

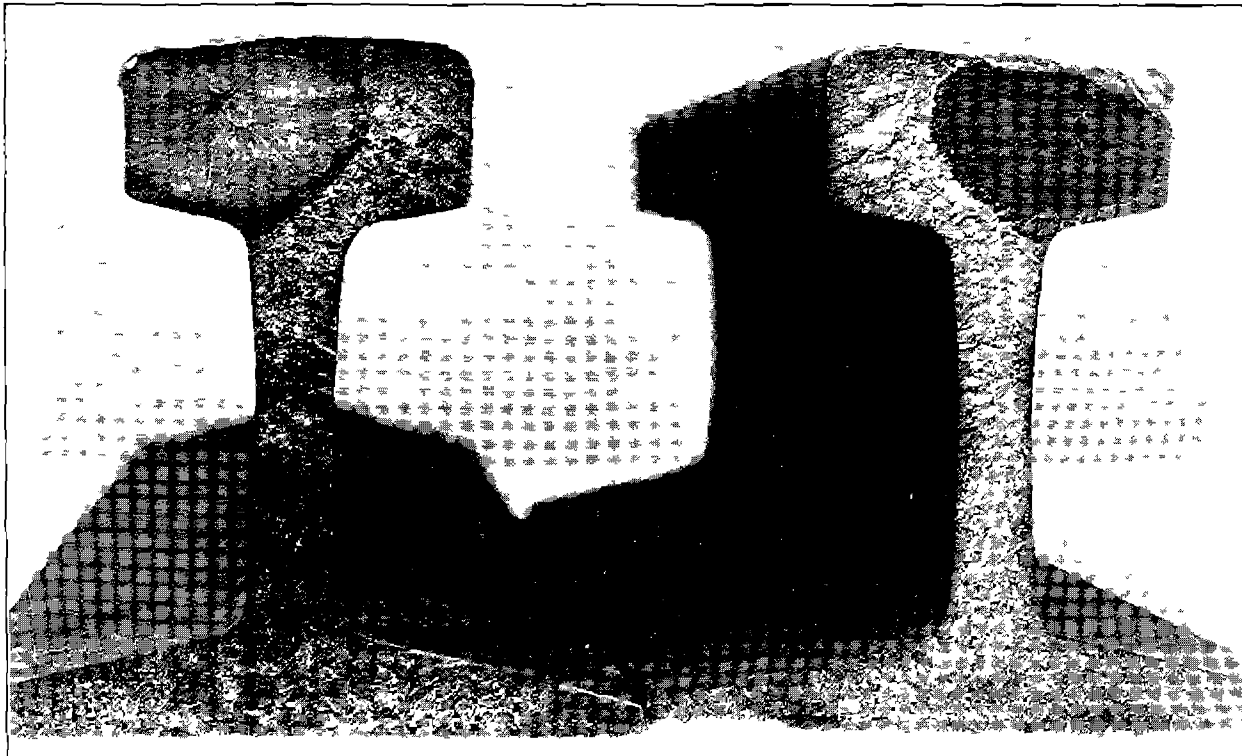

FIG 6—Appearance of the opposite faces of the transverse fissure first to break Leaving and receiving ends respectively of fragments A and B

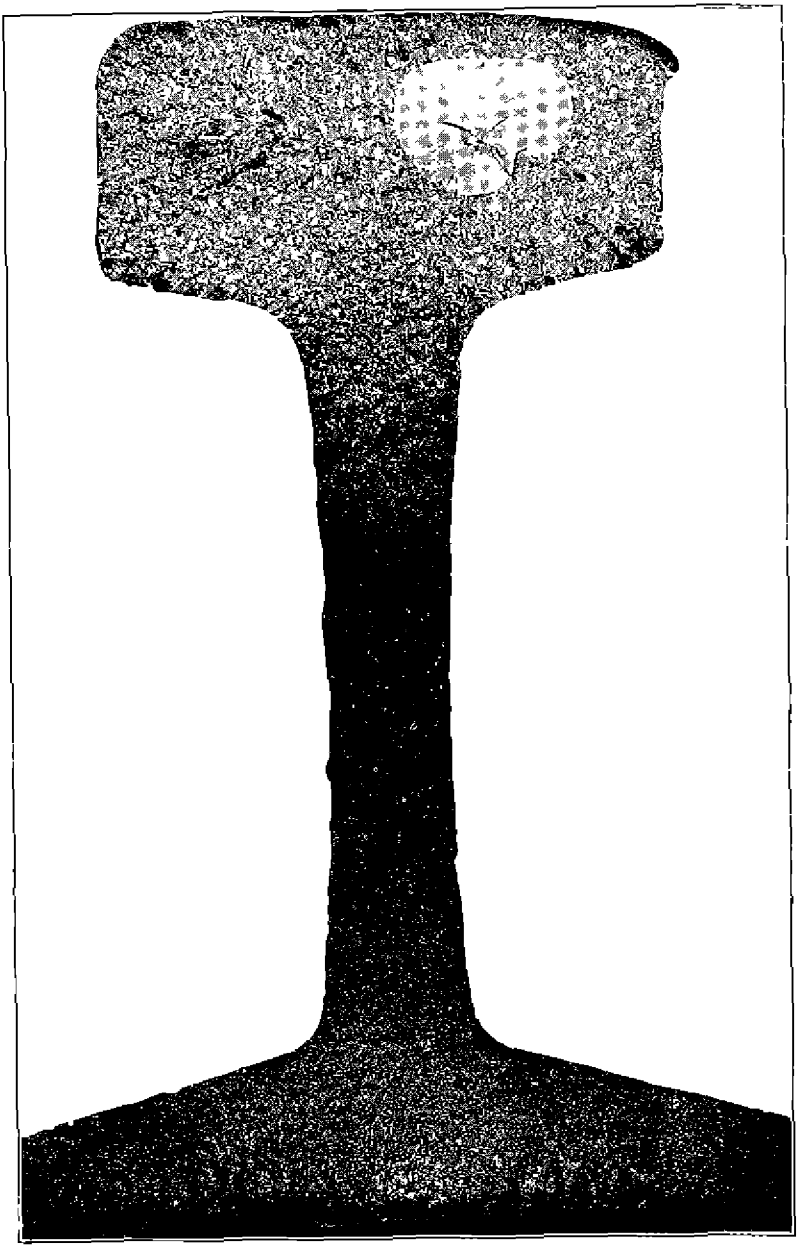

FIG. 7.—Partially formed transverse fissure revealed by hammer test of fragment A

Mill analyses of the heats represented by these rails were as follows:

Heat	Rolled	C	Mn	P	S	Si	Remarks
17054	Oct. 30, 1918	0.71	0.87	0.028	0.035	0.103	Rail of this heat caused the accident.
76990	Oct. 29, 1918	.63	.77	.030	.029	.127	
76995	Oct. 30, 1918	.66	.71	.028	.034	.165	
79997	do	.69	.80	.026	.036	.120	
72569	Feb. 12, 1914	.65	.87	.034	.037	.116	Curve worn rail.
20690	Dec. 3, 1910	.69	.75	.022	.021		

Rail of heat number 20690 represented a transverse fissured rail, 85 pounds weight, which caused a derailment on the Southern Railway on August 2, 1925. In this accident the engine and tender passed over the broken rail successfully, the cars which followed being derailed. The age of this rail was 14 years, 4 months.

Check analyses of heat 17054, made in the laboratory of the St. Louis-San Francisco Railroad at Springfield, Mo., confirmed the mill analysis. At Springfield chips were taken from rails of ingot letters C and F, at two places on each, in line longitudinally with the transverse fissures which they displayed, and at corresponding places on the opposite side of the head. The composition was practically the same in each rail and at each place.

Prior to taking out chips for chemical analysis, the micro structure of rails 17054 C and F was developed by picric acid etching, the results being shown by Figures Nos. 8 and 9. Substantially the same structure was displayed by each, with no peculiar characteristic in the vicinity of the transverse fissures.

Fragment F of rail 17054 C, Figure No. 5, was used in an examination of the structural state of the steel at different depths below the running surface of the head. The metal was planed off in successive stages and the rail pickled in hot hydrochloric acid at each stage. Figure No. 10 a, b, c and d are photographic views of the pickled surfaces at depths of one-half, five-eighths, three-fourths, and seven-eighths inch, respectively. The surface was clear at a depth of one-half inch. A few crosswise cracks appeared at five-eighths-inch depth. Again the head was nearly clear at three-fourths-inch depth. At seven-eighths-inch depth numerous cracks appeared on the pickled surface. The nuclei of transverse fissures are seldom located so far down as the surface last pickled.

Pickling tests were made with fragment C, of Figure No. 5. At a depth of one-fourth inch the surface was clear. At three-eighths inch down two short oblique cracks were displayed. At increased depths the pickled surfaces showed pronounced markings. Figure No. 11, a, b and c show the appearance of the flaky metal encountered at depths of one-half, five-eighths, and three-fourths inch, respectively. The structure of the rail showed horizontal laminae. It is understood, of course, that pickling puts some of the metal into solution, and that prolonged exposure in the bath greatly exaggerates the markings which represent the structural state.

The head of rail 17054-F was planed off and pickled. Figure No. 12 shows its appearance at a depth of five-eighths inch. The characteristic feature here is the presence of several incipient transverse fissures and a shattered zone on the gauge side of the head with the central core nearly free from these manifestations. These markings are chiefly outside the zone of shrinkage cracks, and from their position would seem attributable to the action of wheel loads only.

Figure No. 13 illustrates the pickled surface of a 130-pound rail from the Baltimore & Ohio Railroad, planed off to a depth of three-fourths inch. Incipient transverse fissures are displayed in echelon from the gauge side of the head in steps toward the middle of its width. The short longitudinal cracks shown are believed to represent acicular slag streaks.

Figure No. 14 illustrates the presence of an incipient transverse fissure in a rail from another source. It represents an incipient fissure on the gauge side of the head of a 105-lb. rail, from the New York Central Railroad. This rail displayed a transverse fissure in service. The head was planed off to the depth of the nucleus of the adjacent fissue and pickled, showing no shrinkage cracks. A duplicate specimen also showed clear metal, that is, no zone of shrinkage cracks.

The examination of the rail responsible for the present accident and other rails from the section of destroyed track displayed no feature uncommon in the tests of other rails. Two rails of the same heat displayed transverse fissures. Others rolled the same month and year and having practically the same chemical composition neither showed transverse fissures in the track nor in the tests subsequently made in quest of them. No reason has been established why fissures were displayed in some parts of these rails and not in other parts, nor why the rails on one side of the track should display transverse fissures while those on the opposite side were exempt from their formation. The problem apparently is one of durability in respect to the endurance of complicated track stresses concerning which indexical features pertaining to primitive properties, or structural state of the rails, have not been established by means of which

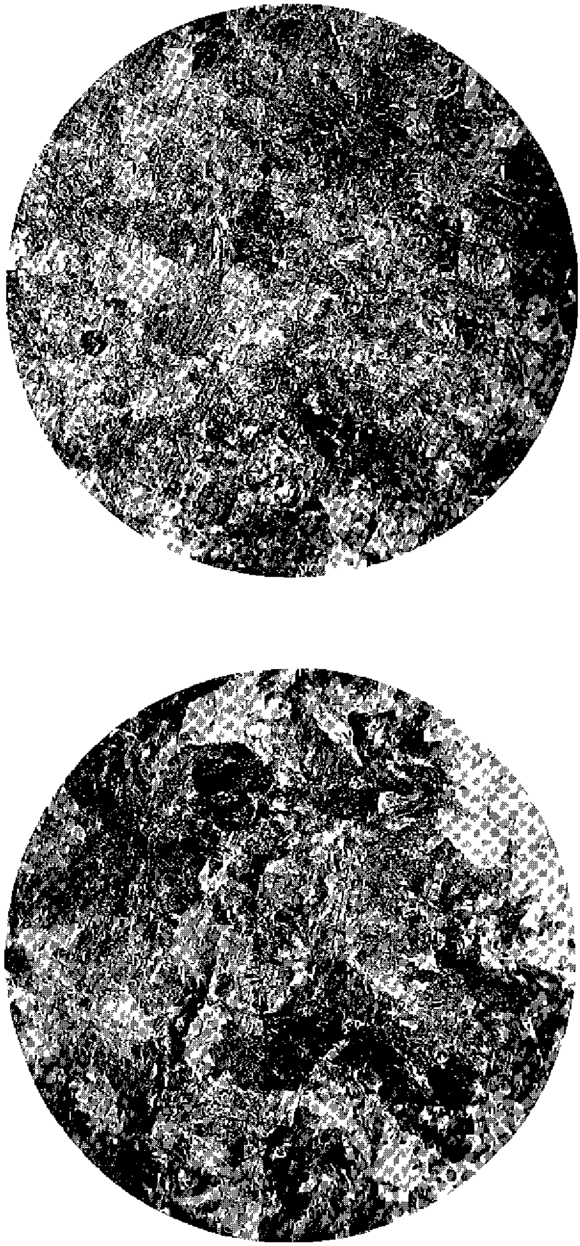

Fig 8 —Microstructure of rail 17054C Zone of transverse fissure and opposite side of head Magnification 100 diameters

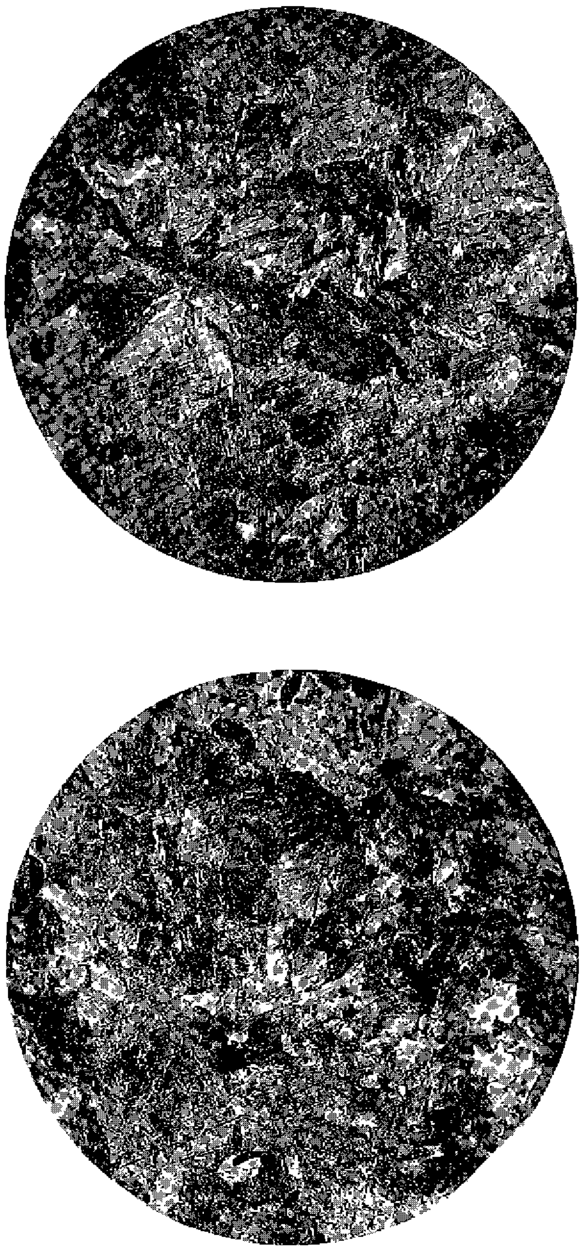

FIG 9.—Microstructure of rail 17054T zone of transverse fissure and opposite side of head Magnification 100 diameters

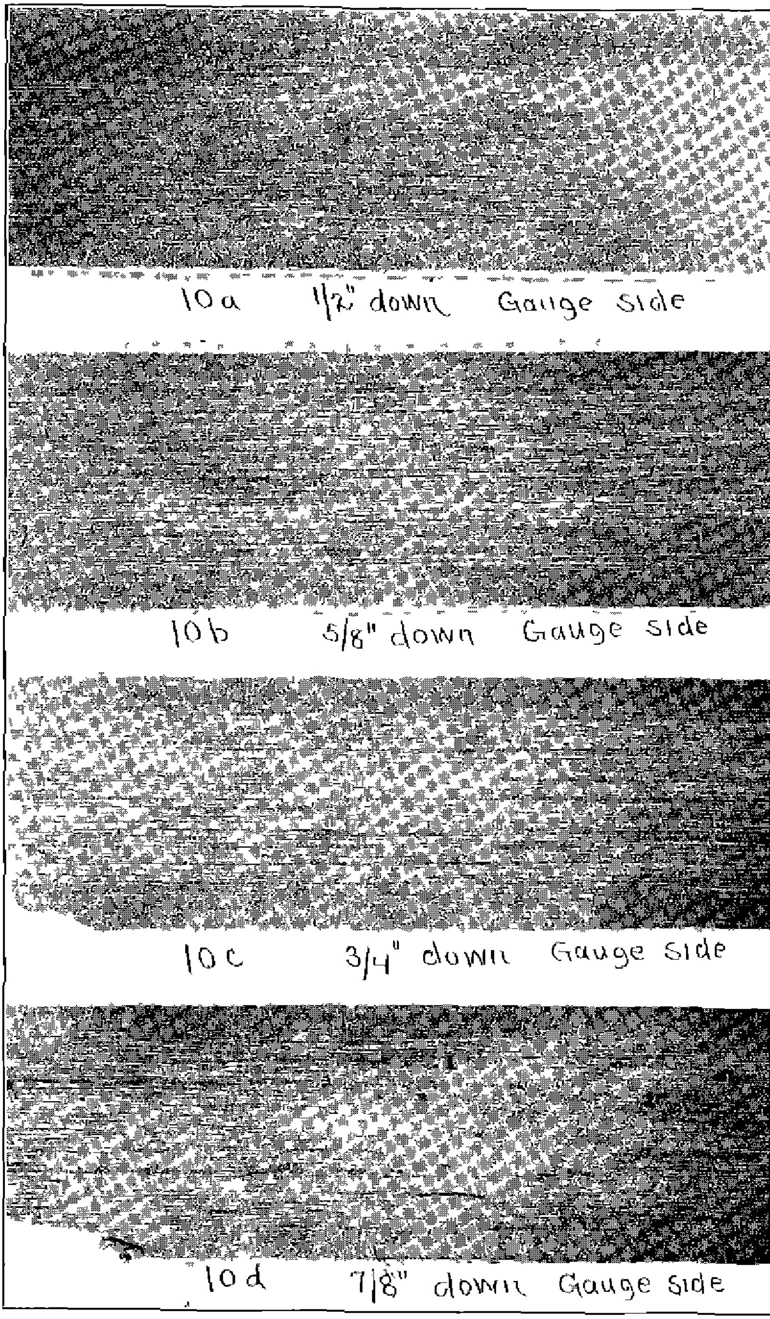

Fig. 10—Head of rail 17054C fragment B planed off in successive stages, surface pickled at each stage

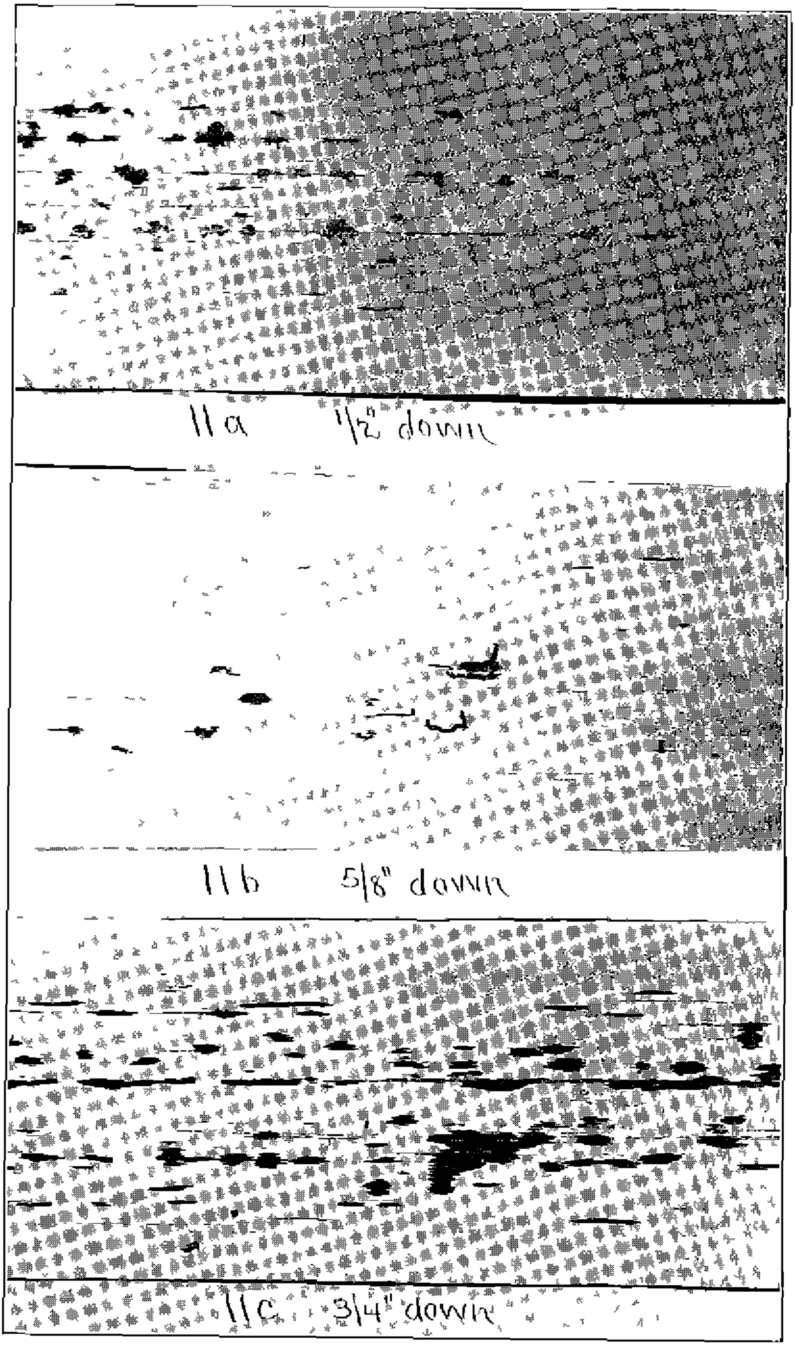

FIG 11 —Head of rail 10754C fragment C, planed off in successive stages surface pickled at each stage

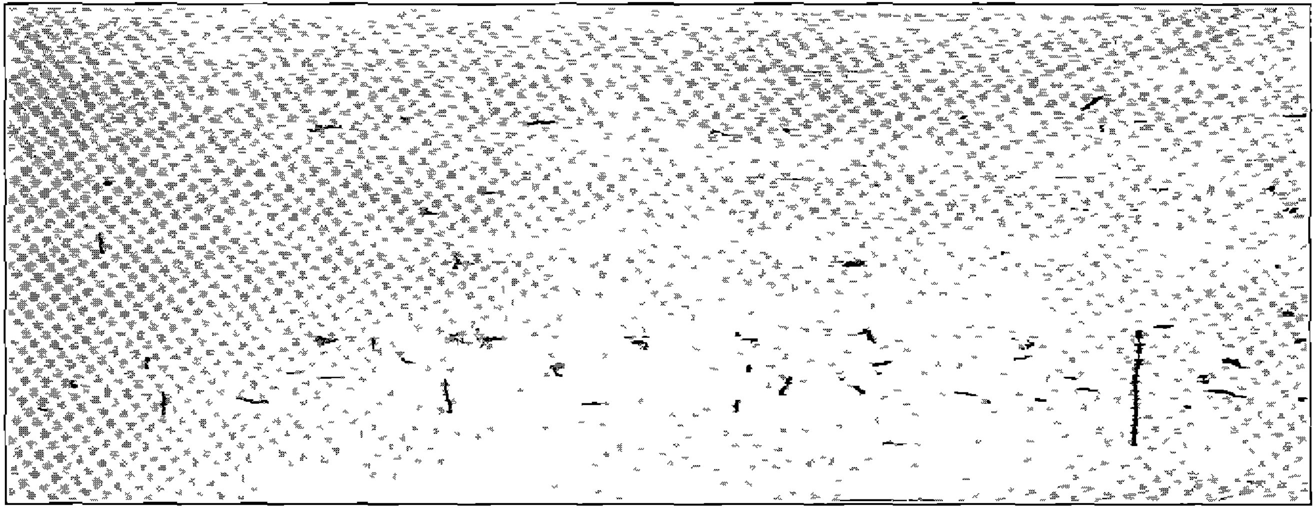

FIG. 12.—Head of rail 17054F, planed off 5/16 inch and surface pickled. Incipient transverse fissures and shattering cracks located on gauge side of the head.

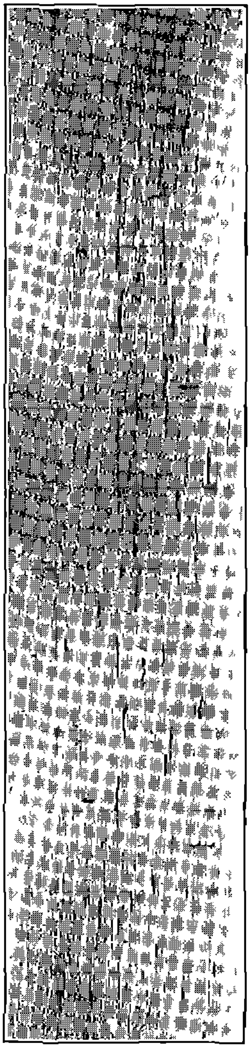

FIG. 13.—Head of a 130-pound rail planed off ¼ inch and surface pickled. Incipient transverse fissures from gauge side inward and also longitudinal slag cracks.

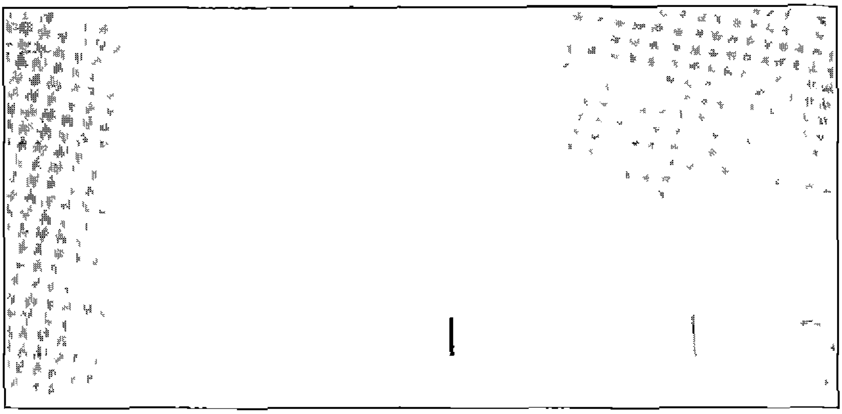

FIG. 14.—Head of a 105-pound rail planed off to depth of nucleus of a transverse fissure displayed in the track surface then pickled. Incipient transverse fissure revealed on gauge side of the head. Surface elsewhere clean.

the approach of rupture may be recognized or predicted when it will take place under given conditions of exposure

REVIEW OF THE SUBJECT OF TRANSVERSE FISSURES

This occasion seems opportune to review the general subject of transverse fissures, referring to the time when first recognized as a distinct type of rail fracture, their early appearance and the increased number of examples which have since been reported, together with the explanation of their occurrence, and the reason why fractures of interior origin and development take place in the heads of rails

A transverse fissure, as a distinct type of rail fracture, was first brought to notice in the report of the Interstate Commerce Commission on the accident of October 25, 1911 on the Lehigh Valley Railroad at Manchester, N Y A fracture was there displayed in the head of the rail of interior origin The metal of the head was partially separated in a vertical plane at right angles to the axis of the rail It was a tensile fracture, in which the metal had yielded to longitudinal forces

As one of interior formation it was recognized that such a fracture was caused by the action of some component which had not hitherto been taken into consideration as a factor in the rupture of rails Under bending stresses, as a beam, the greatest range in fiber stresses is found in those elements most remote from the neutral axis of the rail, in the extreme fibers at the top or the bottom of the rail In the display of transverse fissures those extreme fibers remain unruptured, while elements exposed to only a fraction of the maximum bending range were those which first ruptured The action of an independent longitudinal force was necessary to account for this fracture of internal inception and growth Familiarity with the effects of the cold-rolling action of wheels in setting up internal strains of compression in steel at once pointed to the necessary component and thus explained the raison d'être of a transverse fissure

A zone of metal at the top of the head acquires a state of internal compression from the impinging pressures of the treads of the wheels on the running surface of the rail These internal strains of compression are counteracted and balanced by strains of tension set up in the interior of the head Transverse fissures have their origins in this interior zone of metal This explanation of the development and display of an interior fracture, based upon a law of physics that tensile fractures must occur in zones exposed to tensile strains, and can not occur in zones in a state of compression, was so self-evident and axiomatic that no extended remarks were offered in the original report on this type of fracture

Among those familiar with the treatment and the working of metals the presence of internal strains and their possible culmination in rupture are matters of common knowledge Great care is ordinarily exercised that such influences do not attain destructive limits Outside of such circles a limited degree of attention has been given this important branch of the physics of steel

The early reception of the announcement of a transverse fissure, a fracture forming within the head of a rail, was one of doubt or denial Several years elapsed after the publication of the report on the Manchester accident before general and serious attention was given this type of fracture So vague were the impressions entertained by some engineers that a large number of new rails were broken in quest of transverse fissures, with, of course, negative results The transverse fissures displayed in the Manchester accident each covered a large part of the cross section of the head of the rail, which circumstances themselves would indicate the futility of a search directed upon new rails Following these immediate efforts investigative work was not actively pursued for a time Many conjectural explanations, however, were offered in the early days of transverse fissures, some remotely bearing upon the subject It is believed these have been generally abandoned by their proponents

Classified reports of rail fractures for a few years succeeding the Manchester accident did not specify transverse fissured rails as a distinct group Some rails escape proper classification even at the present time A report of the commission in 1923 on the prevalence of transverse fissures on 17 railroads showed the location by mile posts of over 8,000 fissured rails The number of known transverse fissures at the present time exceeds 22,000, representing several thousand heats of steel [1]

Transverse fissures appear in rails of different chemical composition, with tendency greatest in the hardest steels High-carbon steels have displayed them in large numbers They appeared in chrome-nickel steel rails prior to the Manchester accident They are found in rails from all parts of the ingot On some roads they predominate in rails from the upper part of the ingot, on other railroads chiefly from the upper and lower parts Again, they have appeared in the D rails in greatest numbers up to the age of four years, after which the B rails equalled in numbers the D rails

[1] Bulletin of the American Railway Engineering Association March 1927 states that 22 469 transverse fissured rails have been reported up to January 31 1926 and that they are occurring at approximately 4 000 per year

They are found in rails of different weights per yard. They have not been reported in very light weight rails, undoubtedly due to mild track conditions. The heaviest rails now in use, up to 136 pounds weight per yard, are not immune from their formation.

The display of transverse fissures is not confined to any one section of the country. They are most prevalent, however, in territory where traffic is heaviest. The influence of density of traffic is clearly shown on double track road. Rails which carry the greatest tonnage display the most fissures. Low rails of curves commonly display more transverse fissures than high rails. In regard to the rails themselves, fissures predominate on the gauge side of the head. There is reason for believing that speeds of trains have an influence, high speeds accelerating their development.

The time required for their display varies from a few months to a term of years. The interval of time in the track from 5 to 15 years embraces the majority of the fractures. The extreme range is from a few months to 30 years. Bessemer rails chance to be among the oldest. Hard steels, density of traffic, and wheel loads are factors the influences of which are paramount in the development of transverse fissures.

The weight of the rail, or specifically the size of its head, within limits, does not exert a substantial influence in the relations of the internal strains set up therein. The volume of metal disturbed by the wheel loads is regarded a vital factor in relation to the development of transverse fissures. It is not altogether the intensity of the impinging pressures in a strict statement of the case, but the progressive change of intensity of pressure from center of effort to circumference that exerts a modifying effect on the physical properties of the steel. Following the laws which govern in cases of cubic compression it is the progressive difference in pressure on circumambient particles of the steel that affects their properties, rather than the total pressures on each. The dimensions of the heads of rails, however, do not bring into consideration this ultimate phase of the problem. As the matter stands the intensity of the impinging pressures between the tread of the wheel and the running surface of the rail and the volume of metal disturbed, the latter depending upon the magnitude of the wheel loads, constitute the factors which introduce internal strains that cause or tend to cause the formation of transverse fissures. This is a general statement of the case and one which attaches to the conditions of all rails.

No mystery surrounds the formation of a transverse fissure, nor has there been one at any time. The explanation is simple. There is an exterior strain of compression, an interior strain of tension

The metal is fractured by tension Rupture is possible only by tension or shear

Another question, however, was at once injected into this matter, a distinct one, having no relation whatsoever as to why the origin of the fracture was located in any definite place, interior or exterior It had to do only with the matter of endurance, why one steel differed from another in its ability to resist track or other stresses That question is now uppermost and whether the margin in strength and endurance has not been reduced in some cases to a narrow margin, in others obliterated

A perfectly legitimate question is raised in respect to endurance which all would like to know about By concurrence of opinion engineering practice has established standards of stresses to which important structural members may be exposed or not exceeded The stresses in tensile members are restricted to certain values, in pounds per square inch of sectional area Likewise compression members are restricted to certain unit stresses, modified in long columns according to ratio of slenderness Coming nearer to railroad engineering, the manufacturers of ball and roller bearings establish definite limits to the loads on roller paths It has not come to notice that any restrictions have been imposed, or even advocated, upon the loads which shall be concentrated on the head of a rail However, this matter was referred to but not acted upon in an item of the American Railway Engineering Association in its program for 1924 which read "The determination of the maximum permissible wheel loads imposed by the passage of wheels of various diameters"

There is no real occasion to appear astonished or awe stricken over the thousands of rails which are displaying transverse fissures in the tracks The development of interior fractures is entirely consistent with our knowledge of the strains which are set up in the interior of the heads of rails by action of wheel loads on their surfaces The rails are obeying a physical law by which all members which sustain loads, carried upon wheels, are governed

Descriptive remarks will follow upon influences to which rails are exposed in fabrication and in use Special tests are necessary to illustrate the action of certain forces which affect rails relating to changes which occur within limits too narrow to admit of study in the rails themselves

COOLING STRAINS OF FABRICATION

Cooling strains are set up in all rails They are set up in all cast, forged, and rolled shapes, the magnitude of which depends upon the rate of cooling The more rapid the rate of cooling, the more intense the internal strains, culminating in spontaneous rupture in cases of sudden quenching Relief from cooling strains is attained by slow cooling from elevated temperatures Mass and shape have an influence on the rate of cooling and, therefore, upon the magnitude and disposition of the acquired internal strains

The cooling strains in rails have been measured on many occasions This is done by establishing gauge lengths on certain elements along the length of the intact rail, then detach the strips on which they are located, and remeasuring their lengths after they have been detached An initial state of compression is shown by expansion in length of the strip, tension by its contraction in length The strains thus measured are converted to equivalent stresses by reference to the modulus of elasticity of the metal taken in round numbers for steel at 30,000,000 pounds per square inch On a gauged length of 10 inches each increment or decrement in length of a ten-thousandth of an inch therefore represents a stress of 300 pounds per square inch of compression or tension, respectively

Figure No 15 illustrates the places along the length of the rail where strains of compression or tension are found after normal conditions of cooling, also zones where shrinkage cracks occur Cooling strains are greatest at the edges of the flanges, least in the metal of the head Thin flanges acquire higher cooling strains than thick ones The head cools more slowly, on account of its mass, and acquires strains of less magnitude Rails of the heavier sections commonly show moderate cooling strains in the head

Rails emerge from the last pass of the rail mill at different temperatures in different parts of their cross section They are cambered to compensate for this difference in temperature between the head and the base of the rail, taken as a whole No compensation of this kind is possible for the difference in temperature between the flanges of the base and the thicker metal at the junction of the web and the base, nor for local strains at the fillets of the web Neither can there be any mechanical adjustment for strains between the peripheral and the interior metal of the cross section at any part of the rail So-called balanced sections have little to commend themselves in this respect

A rail is certain to have strains, internal and external, lengthwise and crosswise, in its primitive state from the rail mill As a whole the rail has a definite neutral axis from whence its section modulus is derived It also has a number of neutral axes with reference to its cooling strains

Placed within the outlines of the rail as shown by Figure No 15, are stars indicating the location of zones where shrinkage cracks occur At some period during the operation of cooling, internal strains of tension are set up, which occasionally are of sufficient magnitude to cause interior cracks in the rail at these two zones It

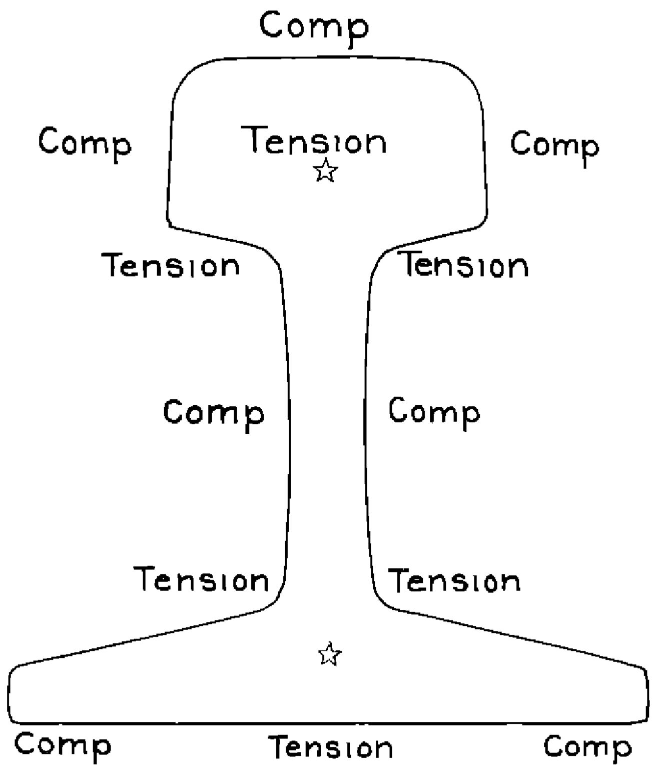

FIG. 15.—Locations of strains of compression and tension in rails of normal cooling. Stars indicate zones where shrinkage cracks occur.

has been found that these shrinkage cracks do not extend to the hot sawed ends of the rails. They cease at approximately the same distance from the hot sawed end as the distance in laterally from the periphery to the shattered zone. This evidence fixes the period of their formation subsequent to the hot sawing operation. The character of the cracks leads to the belief they form while the central core is at a fairly high temperature, when the interior metal has but little tensile strength but is in a plastic state.

Shrinkage cracks are very minute and may escape detection microscopically or macroscopically. They contain no foreign inclusions. They are more readily detected with the microscope on a medium polished surface than on a highly polished one. Decarburizing the metal brings the walls of the cracks prominently into view. Draw filing often shows the location of minute cracks, the fine chips from the file becoming polarized and arrested at the cracks. Pickling in hot acid enlarges the cracks by putting some of the metal into solution. The latter method of examination is a convenient one for their immediate detection but destroys essential evidence in their study.

Shrinkage cracks are oriented in different directions, in planes normal or oblique to the axis of the rail. They signify the relief, partial or complete, of the cooling strains of fabrication. They should not be confused with longitudinal streaks and seams of considerable length, which represent acicular slag inclusions. Slag or silicate globules in the ingot are drawn out into acicular streaks in the finished rail.

Shrinkage cracks are held by some as essential antecedent conditions for the inceptions of transverse fissures. In some cases they do furnish the locus, incipient fissures having been found originating in shattered zones. Other transverse fissures have been located unassociated with shrinkage cracks, and still others in rails where search has revealed no shattered metal whatsoever.

This feature of shrinkage cracks, however, is deserving further observation and study. Cumulative data on the prevalence of shrinkage cracks in transverse fissured rails of different ages would assist in forming judgment on their influence, whether an accelerating or a retarding one, and whether they concentrate or diffuse the forces which tend toward the formation of transverse fissures. Shrinkage cracks represent the relief of shrinkage strains by reason of the rupture of the metal. As such they would seem retarders in the development of transverse fissures. Sharp, reentrant angles in steel are known to be objectionable, nevertheless it has been shown that a certain augmentation in strength is given by adjacent parts in such cases. Stresses of the kind here referred to do not admit of accurate definition Conclusions as to their effects must be reached by means of service records of the behavior of the rails in order to clarify these obscure points

Shattered zones, similar to those of the head, are found in the metal at the junction of the web and the base No example of a transverse fissure has been displayed in this part of the rail Measured track stresses have shown higher tensile stresses in the base than those of the head, under beam action Hence it follows that bending stresses do not appear controlling factors in the formation of transverse fissures The lower surface of the base, resting on a tie-plate, is exposed to a limited amount of wear, and not infrequently experiences a hammering effect between rail and tie-plate But conditions there are not comparable to the impulses directly received from the wheels on the top of the head Fractures displayed in the head and the base are distinctly different and due to different causes

NORMAL AND ACCELERATED COOLING, ALSO EFFECTS OF GAGGING

Numerical values, stresses pounds per square inch, representing the cooling strains of fabrication are illustrated by figure No 16 for a rail cooled normally in air The stresses here given were present in a 127-pound medium manganese steel rail The manganese content was 1 67 carbon 0 68 Compression stresses of moderate degree prevailed in the periphery of the head Tensile stresses not measured in the central core of the head, required to balance the external stresses, were necessarily of moderate degree Tensile stresses were displayed at each of the fillets of the web, the intermediate portion of the web being in a state of initial compression Higher stresses of compression prevailed in the edges of the flanges than elsewhere

These general relations between the cooling stresses of the head and flanges of the base are maintained in rails normally cooled on the hot bed Attention has sometimes been called to the local cooling of the rail where it rests upon the skids of the hot bed Strain gauge measurements on experimental sections cooled on an iron platform have not shown important modifications attaching to this feature

An active period in the adjustments of internal strains takes place while the rail is cooling on the hot bed The cambered rail at first is shortest along the base The head cools, contracts, and straightens the rail Different parts of the cross section of the rail differ in temperature, consequently pass over the recalescent periods at different times A continual change takes place in the magnitude and relations of the internal strains, some parts being in a state of tension, other parts in a state of compression, with neutral axes intervening

The cooling strains of fabrication may be lowered by retarded cooling or raised by accelerated cooling. Cooling mediums, air, oil and water, emulsions of oil and water and brine each have their peculiar influence. Of these mediums brine is the most energetic, air the least.

Figure No. 17 illustrates the stresses in a 100-pound rail of accelerated cooling. This rail was cooled by an air blast, directed upon the top of the head. It was cooled, from the finishing temperature of the rail mill, with an air blast of 10 pounds pressure of 4 minutes duration. The high values of the initial stresses will be noted, a maximum of 29,100 pounds compression, 11,700 pounds tension making a total range of 40,800 pounds per square inch. To balance these peripheral stresses the internal stresses must have been correspondingly high. A favorable opportunity is presented to develop internal shrinkage cracks by accelerated cooling.

Figure No. 18 illustrates the stresses in a rail which was gagged on one flange. This was a 100-pound rail, air cooled in the same way as the rail last illustrated and described. It will be noted that internal stresses in the flange which received the gagging blow were reversed from the normal state of compression to that of tension. Also that a corresponding reversal of stresses occurred at the fillet of the web and the base on the side struck by the gag. Furthermore that the usual state of tension along the middle of the width of the base was changed to compression. An abrupt transition is shown by the stresses in the opposite fillets of the web and base, 15,900 pounds compression on one side against 9 600 pounds tension on the other. This made a range of stresses at the fillets of 25,500 pounds per square inch, while in the opposite flanges of the base there was a range of 30,800 pounds per square inch.

Figures Nos. 19 and 20 represent two 100-pound rails of accelerated rate of cooling, each cooled from 1,100° F. with an air blast of 10 to 12 pounds pressure, of 6 minutes duration. One rail was gagged on the base. The initial stresses of compression of the base were lowered in values two-thirds. The initial stresses in the sides of the head were reversed from compression to a state of tension. Reversal to a state of tension in the flanges would no doubt have been accomplished if the gagging had been carried further.

The internal strains set up in a beam bent beyond its elastic limit enumerated from the concave side to the convex side are strains of tension, compression, tension, and compression, respectively. To make these remarks clearer, a beam bent beyond its elastic limit springs back a certain amount when the load is removed, until a state of equilibrium of interior strains is established, whereupon the metal at the inside of the bend is put into tension, at the outside of

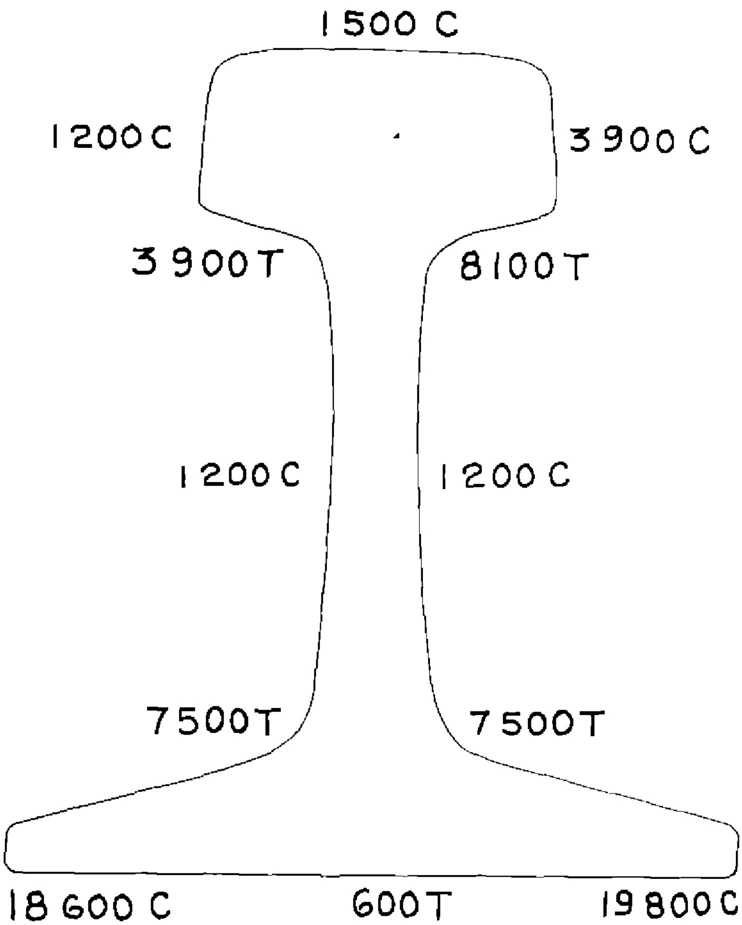

FIG. 16.—Stresses corresponding to the cooling strains of fabrication in a medium manganese steel rail. Weight of rail 127 pounds per yard. Manganese content 1.67, carbon 0.68.

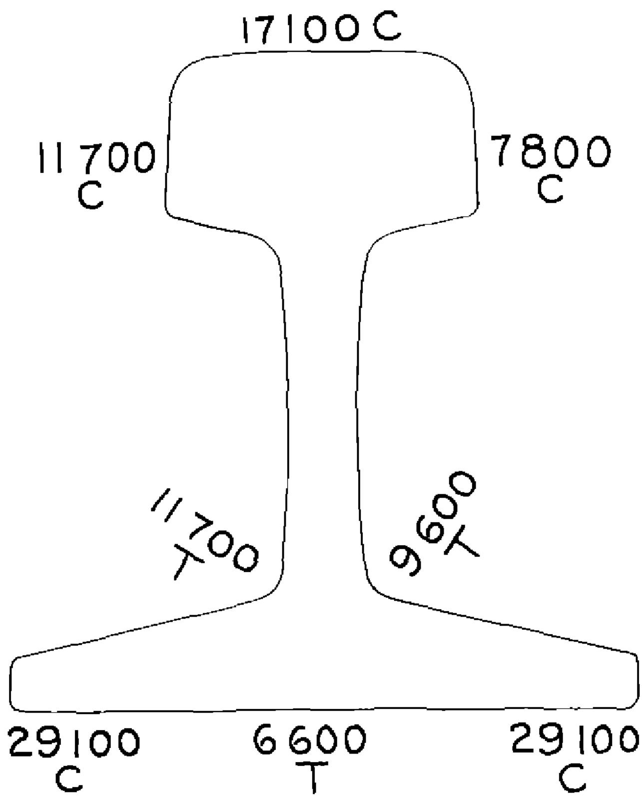

FIG 17 —Initial stresses in a 100 pound rail cooled by an air blast directed on the head 10 pounds pressure of 4 minutes duration

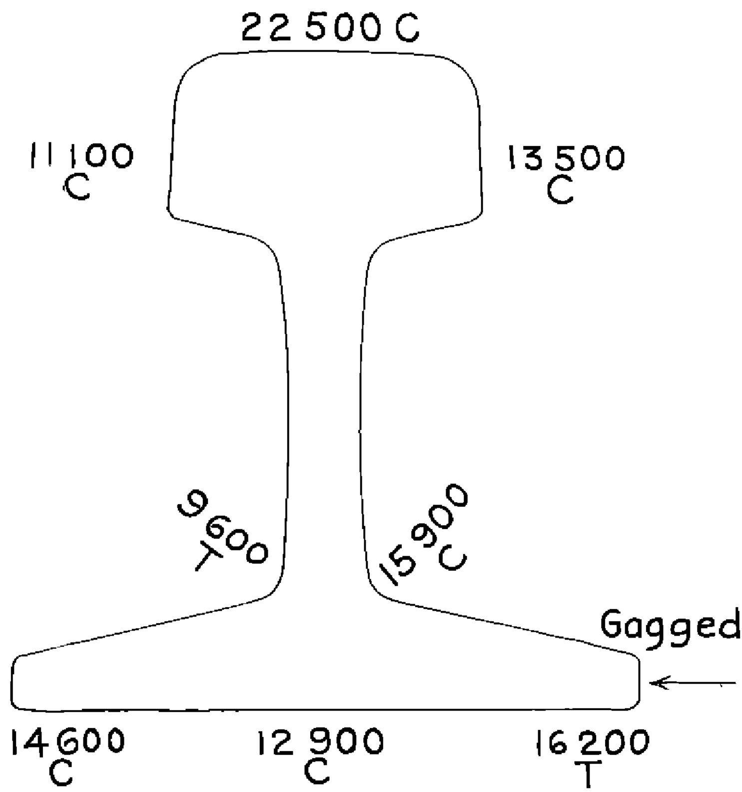

FIG. 18.—Initial stresses in a 100-pound rail reversed from compression to tension by the operation of gagging. Air cooled rail same as Figure 17.

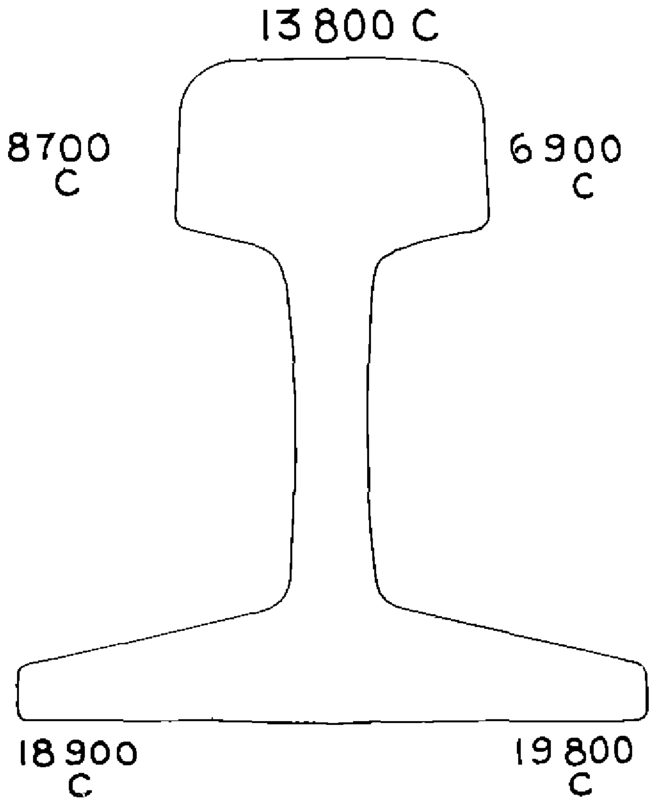

FIG. 19.—Initial stresses in a 100-pound rail cooled from temperature of 1,100° F. by an air blast directed on the head, 10 to 12 pounds pressure of 6 minutes duration.

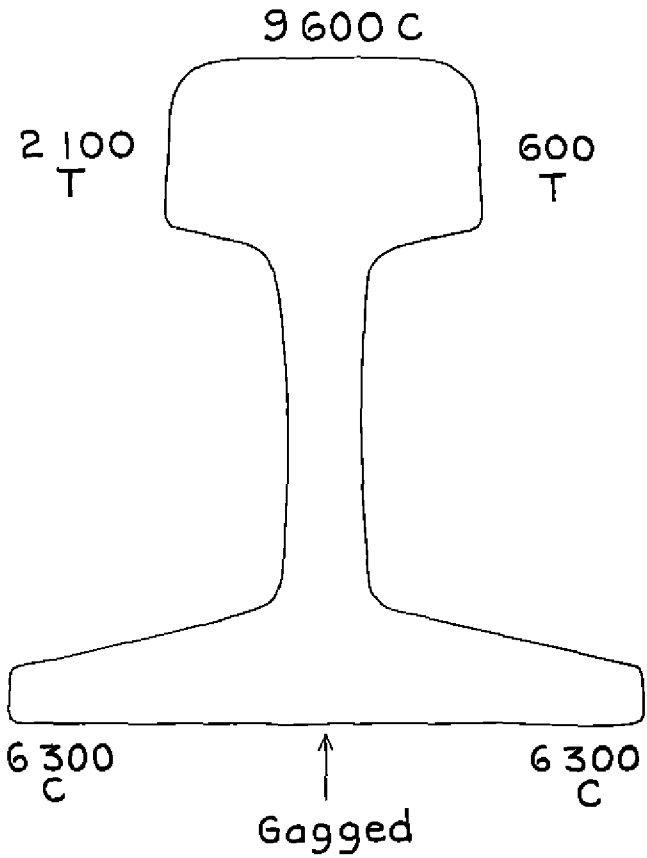

FIG. 20.—Initial stresses in a 100-pound rail after gagging on the base. Air cooled rail same as Figure 19.

the bend into compression, the reverse of the strains in the metal contiguous to the neutral axis, the metal immediately adjacent to the neutral axis not having been overstrained.

This disposition of internal strains, together with the changes in the values of the elastic limits of tension and compression, respectively, which occur in overstrained metal, has a bearing on the initial state of a rail which has been gagged. Internal strains are always in a state of equilibrium, but easily dislocated after cold bending. Bending stresses in the track, which reverse those of the gag, readily cause permanent sets in the rail. The elastic limits of tension and compression, respectively, in hot worked steel are commonly equal, but overstraining in one direction impairs the value of the opposite elastic limit. The operation of gagging, which to be effective must overstrain the metal, therefore impairs the elastic limits.

This feature was illustrated in laboratory tests of a 100-pound rail. After overstraining in one direction permanent sets were developed by reversal of load at one-third the fiber stress at which sets of the same magnitude were displayed before overstraining. The same phenomenon has been illustrated in the alternate straining of steel bars by direct tension and compression. The total primitive elastic range in stress of 100,000 pounds per square inch, 50,000 pounds each of tension and compression, was not retained after once overstraining in either direction. The sum of the two elastic limits thereafter fell much below the original range of 100,000.

This characteristic feature has a bearing on the behavior of steel rails in two ways. Straightening by gagging leaves the rail in a condition susceptible of taking a permanent set in the reverse direction of the gagging, under stresses below its primitive resistance. The impinging pressures between wheel and rail tend to lower the elastic limits of the surface metal of the rail, thereby leading to greater depth of penetration of effect. Still another effect is noticed from which the metal recovers. Overstraining has been found to temporarily lower the value of the modulus of elasticity. Still another illustration, the amount of power, mechanical work, required to rotate a shaft overloaded transversely is notably greater at the start than after a few rotations have been made. Confronted by these many features, it is hardly tenable to ascribe causes of fracture of steel rails in general to undefined mill conditions.

SUCCESSIVE ANNEALING OF DETACHED STRIPS FROM A RAIL

Figure No. 21 illustrates the initial stresses in a 100-pound rail, air cooled from the finishing temperature at the rail mill, with air blast of 6 pounds pressure of four minutes duration, after which

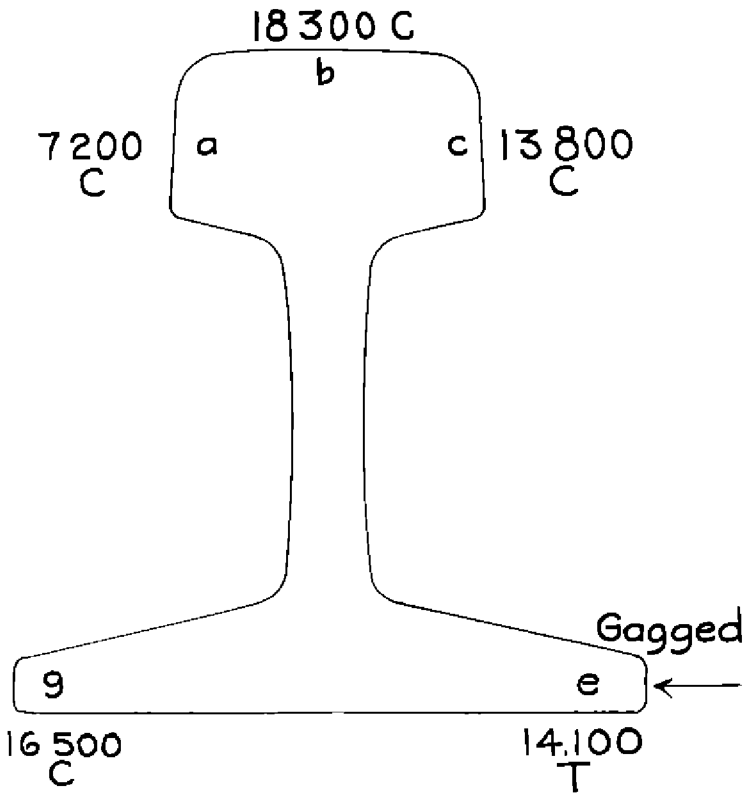

FIG. 21.—Initial stresses in a 100-pound rail, air cooled, gagged on a flange. Strip from head and base annealed.

the rail was gagged on the flange designated by the letter c. The flange which directly received the gagging blow was left in a state of tension, the opposite flange in a state of compression.

The detached strips on which the stresses were measured were subsequently annealed. The strips were successively shortened in length, as shown by the table which follows. Measurements were made on gauged lengths of 10 inches each.

Gauged length	Annealing temperatures				Final equivalent stresses
	1,450°	1,450°	1,600°	1,800°	
a	−0.0115	−0.0159	−0.0265	−0.0405	121,500
b	−.0091	−.0140	−.0250	−.0299	89,700
c	−.0116	−.0167	−.0286	−.0344	103,200
e	−.0082	−.0116	−.0194	−.0289	86,700
f	−.0042	−.0063	−.0158	−.0263	78,900

All strips were shortened as indicated by the minus signs in this tabular exhibit. No fixed relation appeared between the values of the initial stresses in the intact rail and the amounts which the detached strips were subsequently shortened. The stresses in one flange were reversed by the operation of gagging, but this circumstance did not prevent its following the same course as its companion and the other strips. A forging drawn down from a bloom was annealed. Measurements were made on different sides. The shortening was greatest parallel to the direction in which the metal had been forged.

These experiments indicate changes in the density of the steel, suggestive of many interesting lines of inquiry. At a very early date it was found that hardened steel bars would contract in length upon exposure to a moderate rise in temperature, a few hundred degrees Fahrenheit. Two phenomena were simultaneously displayed, dilatation of the steel by reason of rise in temperature, accompanied simultaneously by an opposing contractile movement.

The figures entered in the last column of the preceding table, under the caption "Final equivalent stresses," indicate values corresponding to the maximum contraction of each strip, stresses which would be required to shorten the strips those several amounts if the shortening was done by compressive forces. Conversion to equivalent stresses gives a better opportunity to grasp the significance of these changes in dimensions, expressed in fractions of an inch, than statements of the strains taken alone.

MEDIUM MANGANESE STEEL RAIL—COOLING STRAINS AND ANNEALING OF STRIPS

A group of three figures, Nos. 22, 23, and 24, present results obtained with a medium manganese steel rail of 127 pounds weight per yard, the maganese content being 1.67, carbon 0.68. Figure No. 22 shows the measured cooling strains on 12 gauged lengths displayed when strips from the intact rail were removed. The strains ranged from 0.0033 to 0.0063 inch, representing stresses of 9,900 pounds per square inch *tension to* 18,900 *pounds compression.*

The detached strips were twice annealed in lime, on each occasion at 1,450° F., resulting in the contraction in length of each of the several strips. The total contractions of the detached strips resulting from the two annealings are shown by Figure No. 23. The corresponding values of these strains, expressed in pounds per square inch, are shown by Figure No. 24.

Again it was found that the contractibility of the strips did not bear a fixed relation to the cooling strains acquired by the rail during fabrication. Strips which in the intact rail were under the opposite strains, of compression or tension respectively, when annealed contracted amounts apparently irrespective of their primitive condition. With different tendencies in these individual strips it would seem that some migratory movements might take place in the annealing of an intact rail.

The cooling strains in the flanges of this medium manganese steel rail were higher than usually found in rails of its weight and thickness of flange. Minimum changes during the processes of annealing took place in the lengths of the flange strips. These variations in decrements of length doubtless possess some peculiar significance in the physics of the metal but of what they consist is not known.

Results deduced from the results shown by Figures Nos. 22 and 23 are given on Figure No. 24. The upper set of values refer to the stresses which existed in the rail, as normally cooled in air. The lower sets of values represent stresses corresponding to the measured decrements of length of the detached strips after they had been annealed. A large number of figures placed on a single diagram are apt to be bewildering, but at this time, for comparison of results, it becomes necessary to present them in juxtaposition.

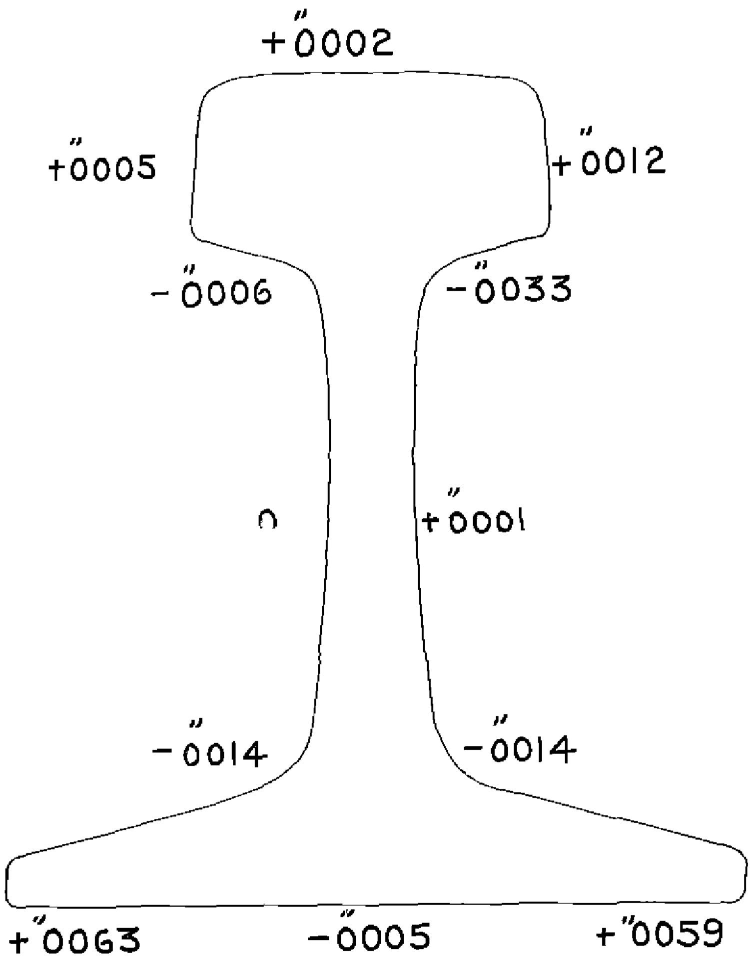

Fig. 22.—Measured strains in strips detached from medium manganese steel rail 127 pounds weight per yard. Normally cooled.

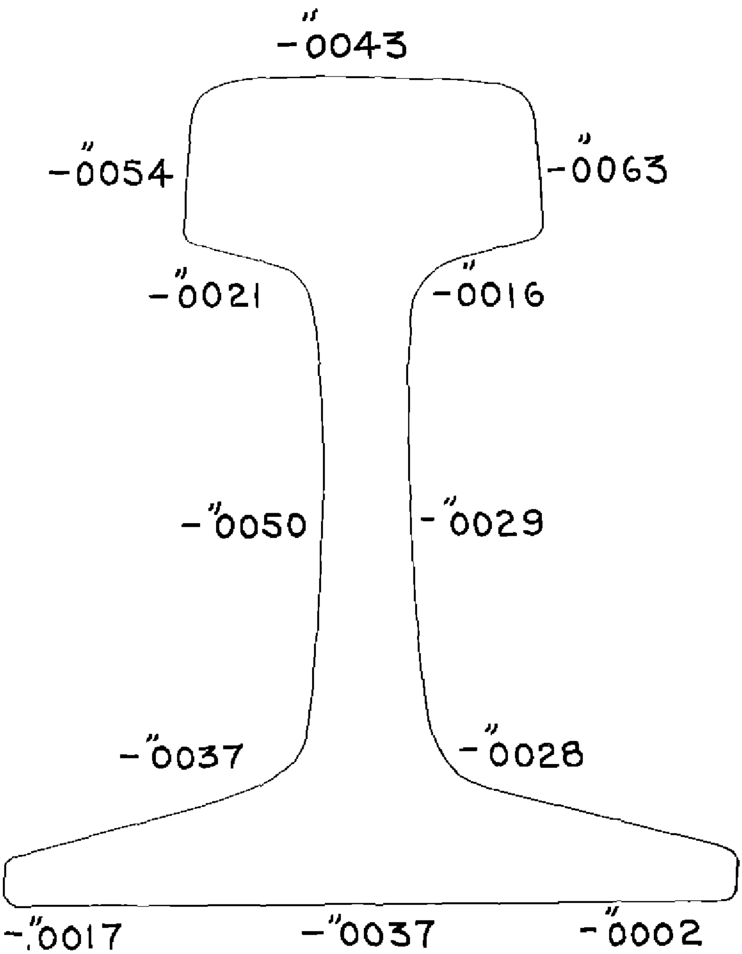

Fig. 23.—Changes in lengths of strips detached from medium manganese steel rail, Figure 22, annealed

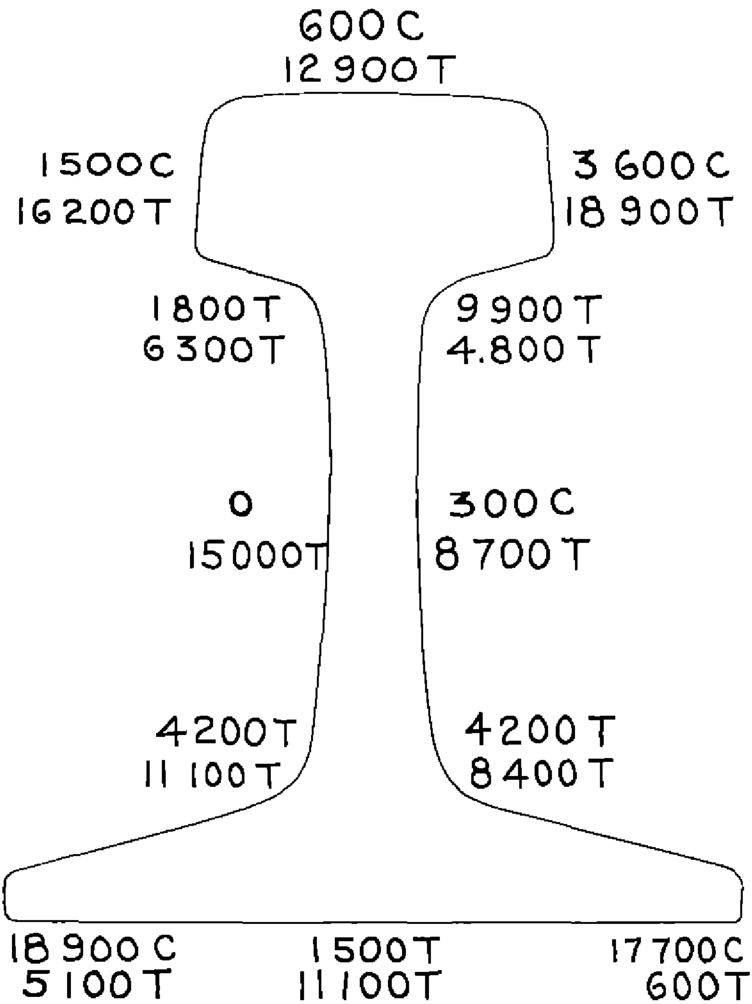

FIG 24.—Stresses corresponding to the strains shown by Figures 22 and 23

FLANGE STRIP SUCCESSIVELY SHORTENED, THEN SUCCESSIVELY LENGTHENED BY HEATING AND COOLING

Tests were made with a strip detached from a flange of a 100-pound rail, illustrating first a successive shortening in length after which it was successively lengthened, each by heat treatment. The strip was taken from a 100-pound rail cooled normally in the air. Figure No. 25 illustrates the internal cooling stresses of fabrication, measured on three elements—at the top of the head and on each flange of the base. The strip detached from flange *g* was successively shortened by heating followed by slow cooling, after which it was successively lengthened by heating followed by rapid cooling.

The results of the test were as follows:

Treatment of strip from edge of flange g

[Strip detached from intact rail +0.0045 inch, 13,500 compression]

Treatment	Successive strains	Equivalent stresses
Heated to 1450° F. and slowly cooled	−0.0100	30,000
Heated again to 1450° F. and slowly cooled	−.0120	36,000
Heated to 1600° F. and slowly cooled	−.0198	59,400
Heated to 1800° F. and slowly cooled	−.0303	90,900
Heated in electric furnace and quenched in water from 485° F.	+.0005	1,500
Heated in electric furnace and quenched in water from 580° F.	+.0010	3,000
Heated in electric furnace and quenched in water from 670° F.	+.0016	4,800
Heated in electric furnace and quenched in water from 840° F.	+.0030	9,000
Heated in electric furnace and quenched in water again from 840° F.	+.0033	9,900
Heated in electric furnace and quenched in water from 1100° F.	+.0041	12,300
Heated in electric furnace and quenched in water from 1300° F.	+.0225	67,500
Heated over open fire and quenched from 1400° F.	+.0510	153,000

Two different phenomena are illustrated in these tests of shortening or lengthening the strip of rail at will by heating and varying the rate of cooling. A physical change resulted from heating and slow cooling; a mechanical result was reached by heating and rapid cooling.

PHENOMENA COMMON TO DIFFERENT STEELS

Other features will be referred to which have a relation to the conditions of exposure of rails in the track, and influences of composition of the steel. Steels of different composition have shown different coefficients of expansion, traceable to the different amounts of carbon present. From this it would appear that carbides of iron have different properties than ferrite. Low-carbon steels and puddled irons have a higher coefficient of expansion than high-carbon steels and cast irons. The influence of the microconstituents is thus believed to be shown. There are similar differences in the specific gravities of the low and high carbon steels. Low-carbon steels are the heavier.

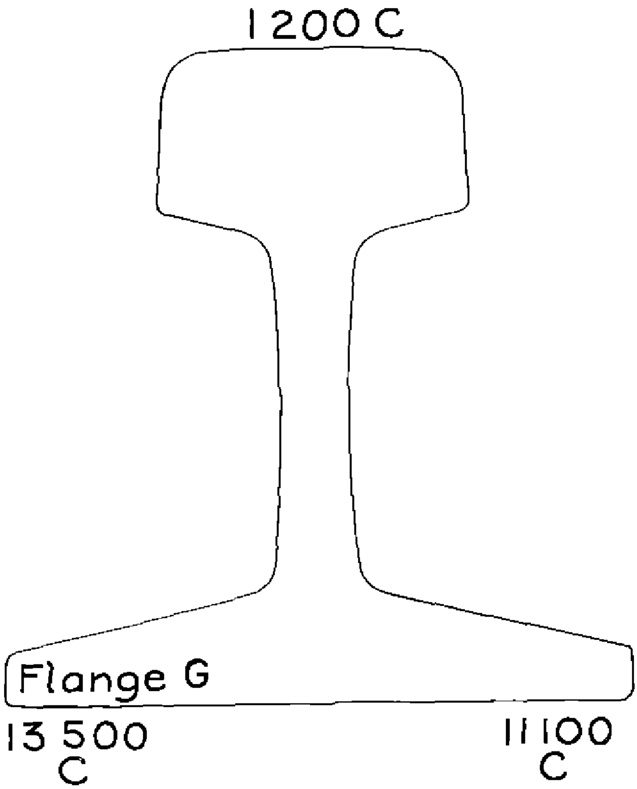

FIG. 27.—Strips from flange G, 100-pound rail normally cooled. Heated strip shortened by slow cooling, lengthened by rapid cooling.

It was early shown that cold rolling diminished the density of steels, cold-rolled shafting being lighter than hot rolled Similarly, steel under stress is lighter than when in repose, as indicated by Poisson's ratio Specific gravity determinations made upon the truncated ogival-shaped ends of tensile specimens have shown lower values than presented in the original hot-rolled bars

The lowering of the value of the modulus of elasticity at higher temperatures, increase in strength, when cold, imparted to the steel by overstraining at moderately high temperatures, ability to permanently elongate different amounts, differing several hundred per cent, according to the method employed, or the entire destruction of this ability, difference in rate of conductivity of heat over the transmission of strains, all of these features are encountered in some degree in the experience of rails in process of fabrication or in use in the track It is comparatively easy to effect the rupture of steel It is a difficult matter to regulate stresses, attain a maximum degree of efficiency and still retain a safe margin in strength The features which have been described are those which steel rails experience, many of them being of common occurrence Reference will now be made to influences and results directly relating to the track

INTERNAL STRESSES IN RAILS ACQUIRED IN THE TRACK

Figure No 26 illustrates the stresses which were present in a 90-pound rail, after service in the track Those of the head were modified by reason of a bond wire having been brazed to the outside, upper edge The structural state was disturbed by the effects of the torch, indicated by the shaded portion of the sketch A cross section of the rail was smooth polished, and the zone of affected metal brought into view by etching with ammonium persulphate

Heating with the torch, for brazing overcompressed the metal for the time being which reversed the internal strains to a state of tension when the rail cooled This brazing which was done near the end of the rail, on the outside of the head was the safest place such heating could be applied without menace to the integrity of the metal The use of the torch on the web or the base of the rail would endanger its safety, leading to its rupture The formation of cracks has been witnessed on the tread of a chilled iron wheel Experimentally a small area of the tread was heated with an oxy-acetylene torch raising the temperature of the metal to a dull red heat During the period of cooling a small network of cracks was formed on the surface of the tread, representing the relief of internal strains of tension

Figure No 27 illustrates the internal stresses of a 100-pound rail from the tracks of the Interborough Rapid Transit Railroad of New York City Its composition was C 0 81 Mn 0 86, P 0 029, S 0 042, Si 0 10 The total tonnage carried by this rail was 300,839 315 tons The wheel loads were fairly light, understood to have been in the vicinity of 15,000 pounds on the motor end of the car Notwithstanding the moderate wheel loads rails in the tracks of this company have not been immune from the display of transverse fissures

Figure No 28 represents a low rail of a 3° 40′ 10″ curve its weight was 130 pounds per yard The average composition of the rails to which this belonged was C 0 682, Mn 0 64, P 0 021, S 0 058, Si 0 077, Ni 0 59, Cr 0 24 The internal strains were measured after the rail had been in the track 16 months The middle element along the top of the head had acquired strains equivalent to 21,000 pounds per square inch compression These are cold rolling strains which come from the impinging pressures of the wheels It is unlikely that the cooling strains of fabrication exert a material influence on the strains later acquired from the impinging action of the wheels that is, in rails cooled normally on the hot bed

The stresses here mentioned are above the average which have been observed but do not represent maximum values in steel rails The measured strains, in any case, are not the maximum ones to which the rail head is subjected They represent the permanent effects of the wheel loads, after the loads have been removed, and not the strains endured by the rail while it is being loaded

There is a discrepancy in values between the measured strains of tension along those elements in which transverse fissures are located and the strains which experimental research show necessary to effect rupture under repeated stresses The difference is in part made up by the increased strains to which the rails are exposed when in a loaded state Experimental results however, represent observations made upon the average behavior of masses of steel, and do not illustrate what happens between elementary parts of the metal, where fractures originate But fractures which occur under the influence of one force, and one force only must be attributed to the action of that force This syllogism aptly applies to the formation of transverse fissures

Figure No 29 illustrates the appearance, in cross section, of an early, puddled, iron rail, of about 40 pounds weight per yard, after etching with tincture of iodine Internal strains in the top of the head were equivalent to 24 920 pounds per square inch compression

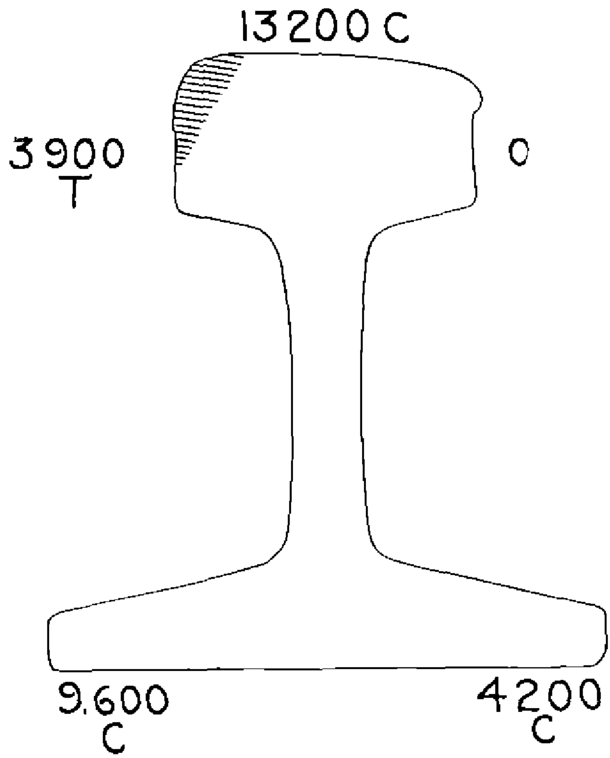

FIG. 26.—Internal stresses in a 90-pound rail modified by brazing a bond wire on side of head.

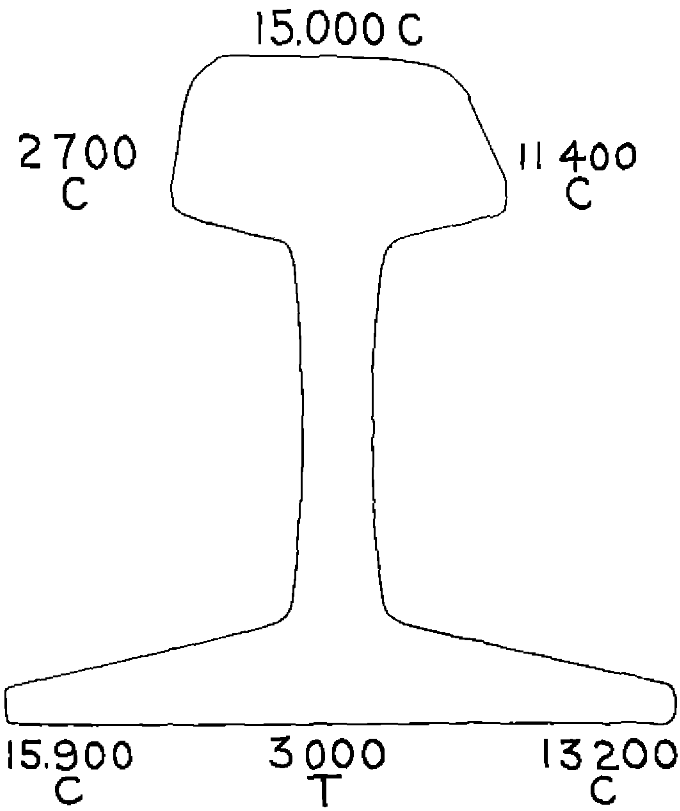

FIG 27 —Internal stresses in a 100 pound rail from the tracks of the Interborough Rapid Transit Railroad, New York City

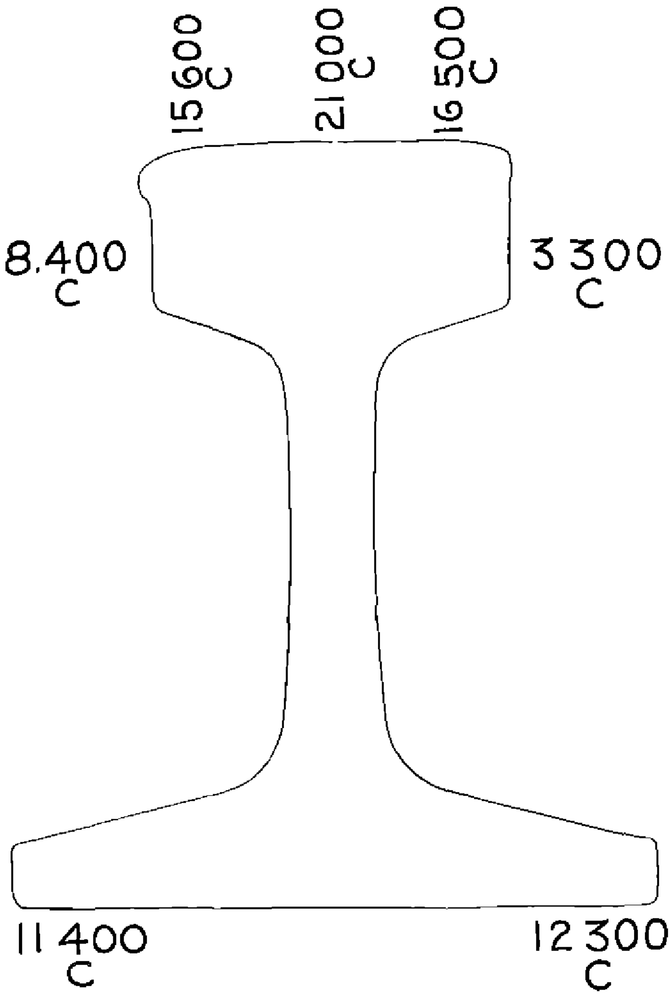

FIG 28—Internal stresses in a 130-pound rail, low rail of a 3° 40′ 10″ curve after 16 months in service

The detached strip on which these strains were measured assumed a pronounced convex shape, with the running surface uppermost, indicating the internal strains were of variable degree in magnitude, greatest adjacent to the running surface.

The lower wheel loads in the days of wrought-iron rails, had their influence on the introduction of internal strains on that weaker metal as they now do on the stronger steel rails. No transverse fissures were ever reported in iron rails but split heads were of common occurrence. The wrought-iron rails yielded by lateral flow of the metal of the head. The laminated structure of the metal was an obstacle to the formation of fissures at right angles to the grain of the iron. Iron is strong lengthwise the grain, weak in crosswise direction. The dissimilarity in behavior of iron and steel has a resemblance to the difference between that of wood and glass.

ABILITY TO RETAIN INTERNAL STRAINS ESSENTIAL IN RAILS

The ability to acquire and retain internal strains is the very property which gives steel the power to endure wheel loads, without which railroads, as we know them, could not exist. The particles of the metal react upon each other. They may be strained up to a certain degree before internal rupture ensues. Mild steels under uniformly distributed loads, will display the phenomenon of continuous flow under stresses far below the impinging pressures between wheel and rail in current railway practice. Mild and medium grades of steels have this period of continuous flow without advance of stress, hard steels rupture in shear before this period is reached.

Hardened steel balls and cylindrical rolls possess a degree of rigidity difficult to obtain in their roller paths. Nothing approaching their rigidity is experienced in wheels and rails of railway practice. Although the hardest steel rails retain their shapes, and under outward appearance appear to be unaffected by wheel pressures, nevertheless they are overstrained, acquire internal strains, which tend to cause and do culminate in transverse fissures. Additional examples might be presented of measured strains in new rails and in those after a period of service in the track. They would merely confirm what has already been stated.

When internal strains from wheel loads are introduced they disturb the relations of preexisting strains. Likewise the removal of strips from one part of the rail disturbs the remaining portion of the cross section, loss of metal by abrasion doing the same. A special test illustrated the reactions in overstrained bar, when portions of its cross section were successively cut away. A rectangular bar bent cold into the shape of a horseshoe has internal strains of ten-

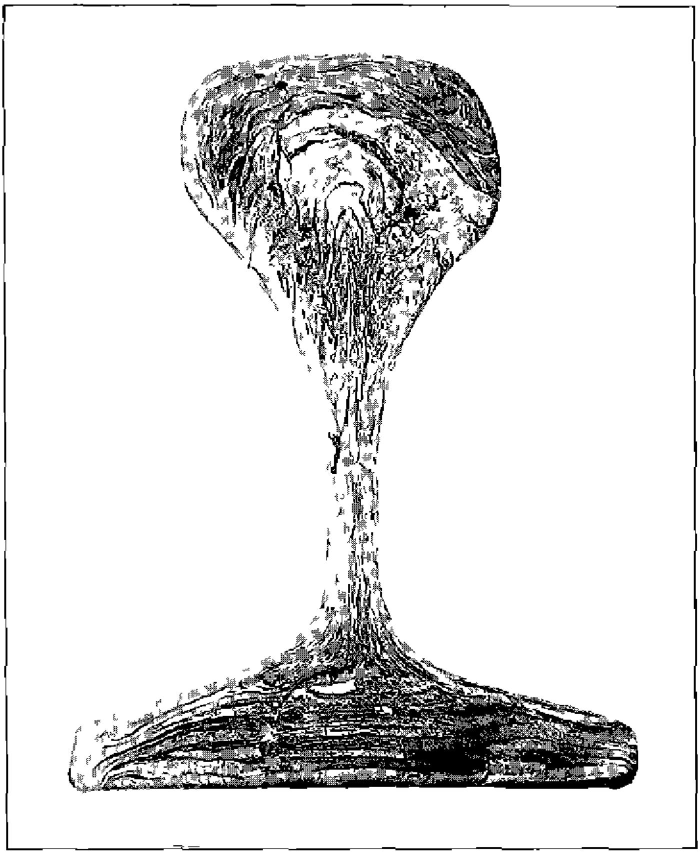

FIG 29 —Cross section of an early wrought iron rail etched with tincture of iodine Internal stress in top of head 24,920 pounds per square inch compression

sion and compression in each of two zones They are disposed in the manner which has previously been alluded to, tension on the inside of the bend, compression on the outside It is indifferent whether metal is planed off the concave or the convex side of the bend, the arms will separate in consequence thereof After sufficient metal has been planed off the movement of the arms reverse and then move toward each other Due to increased leverage, the release of strains is magnified and made easily noticeable at the ends of the arms

Internal strains in rails may be reversed, tension changed to compression or vice versa within narrow limits In thin metal sheets they may be reversed within minute limits Since rupture results from the minute separation of adjacent particles, it is believed that a careful consideration of the phenomena relating to internal strains is not only desirable but necessary in the study of the causes of the rupture of steel rails

COMPOUND TYPE OF TRANSVERSE FISSURES

The terminology transverse fissure was applied specifically to a type of fracture witnessed in a steel rail in which a state of longitudinal strain led to its interior formation It is frequently observed that fractures which originate from a definite cause are diverted from their primitive courses, detaching small fragments or resulting in the complete rupture of the rail Crescent-shaped breaks in the bases of rails are examples of this kind They originate at longitudinal seams or laps, commonly at the middle of the width of the base, and are diverted to the edges of the flange Similar fractures occur in the heads of rails, especially in hard steels A horizontal split head, with origin at an interior streak or seams, is diverted from its course detaching a flattened crescent-shape fragment leaving the rest of the rail intact In other cases the plane of rupture is deflected downward and developed transversely to the axis of the rail A compound transverse fissure is thus formed Surface indications of its presence may be and generally are absent Such an interior fracture presents the same danger in the track as a simple transverse fissure

Figure No 30 a and b represents this type of transverse fissures, with origin at a minute longitudinal streak or slag seam A small silvery oval formed about the acicular seam, at one end of which the fracture was deflected downward Figure No 30a shows this branch, fan-shaped, with nucleus at the end of the acicular seam The silvery oval is shown by Figure No 30b, the extension of the fracture at one end branching upward In this fracture interest attaches to the presence of the minute acicular seam, which led to the display of this compound transverse fissure

Figure No 31 a and b illustrate another compound transverse fissure, at an early stage of its growth Its nucleus was at a longitudinal acicular seam, the origin of a horizontal split head fracture The saw scarfs shown by Figure No 31a were made for the purpose of detaching the top of the rail and revealing the surfaces of the horizontal split head fracture In this example the transverse fissure, which branched from the horizontal split head, took an upward course

Figure No 32 a and b, obverse and reverse of the same fragment, illustrate still another compound transverse fissure The origin of this fissure was at a horizontal split head from which it deflected in a downward direction The transverse fissure separated the larger part of the cross section of the head and extended into the web This was a 100-pound rail, ingot letter G The fracture was completed in the testing machine

The reverse view of the rail shows two nearly horizontal, but slightly inclined, cracks in the upper part of the head These were apparently shearing fractures, the top of the head being cold rolled and separated from the metal below without presence of a longitudinal seam These shearing cracks were obscure, the shorter one hardly perceptible They were made prominent for photographing by draw filing, allowing the polarized chips to gather about the cracks

Figure No 33a illustrates a transverse fissure which, in its development, was arrested by the presence of a vertical split head fracture Its growth however, continued by extending over and beyond the upper edge of the vertical fracture This rail furnishes an example of reverse action to preceding illustrations of compound fractures where horizontal split heads branched, upward or downward, into transverse fissures In the present example the nucleus of the transverse fissure was on the gauge side of the head remote from the vertical crack The transverse fissure was stopped at the vertical crack This rare combination of fractures prompts the query If a large seam or crack possesses the ability to stop a transverse fissure would it be expected that a small seam would possess the ability to start one? The matter resolves itself into the question of orientation, this example tending to eliminate from consideration the presence of longitudinal seams as essential precursors in the formation of transverse fissures If they are not vital, anxiety would center solely upon those shrinkage cracks which are oriented in planes substantially normal to the axis of the rail

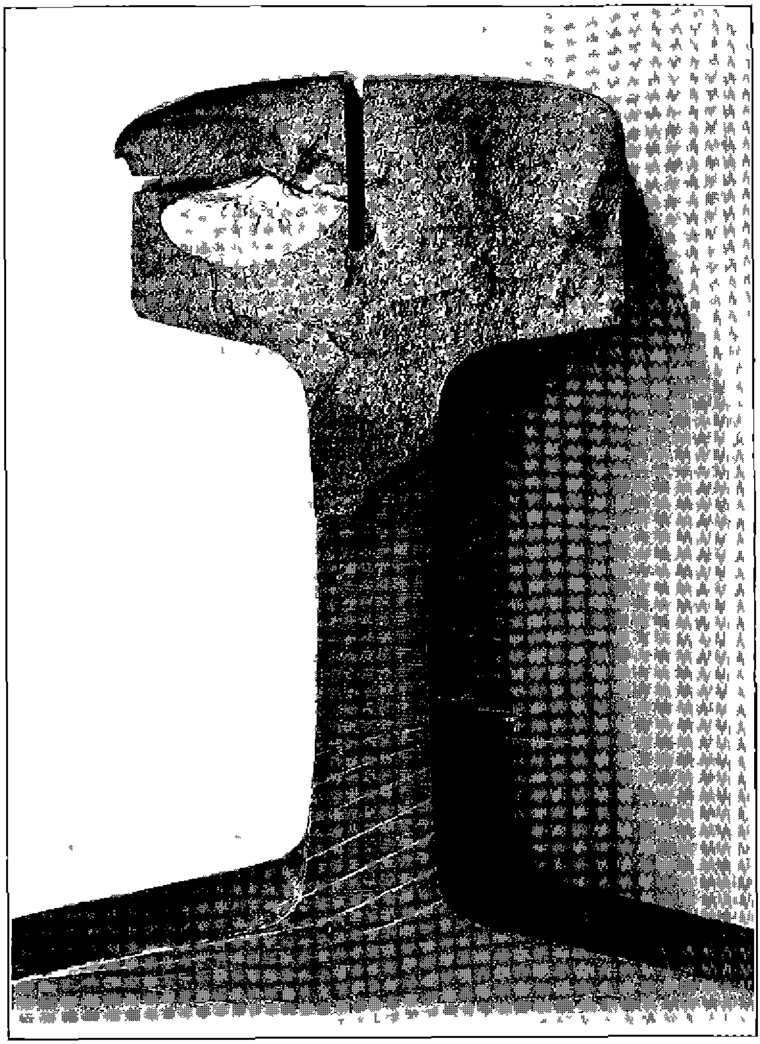

FIG 30*a*

FIGS 30*a* and 30*b*—Compound transverse fissure originating at a small longitudinal seam Vertical development shown by Figure 30*a*, horizontal oval fracture containing longitudinal seam shown by Figure 30*b*

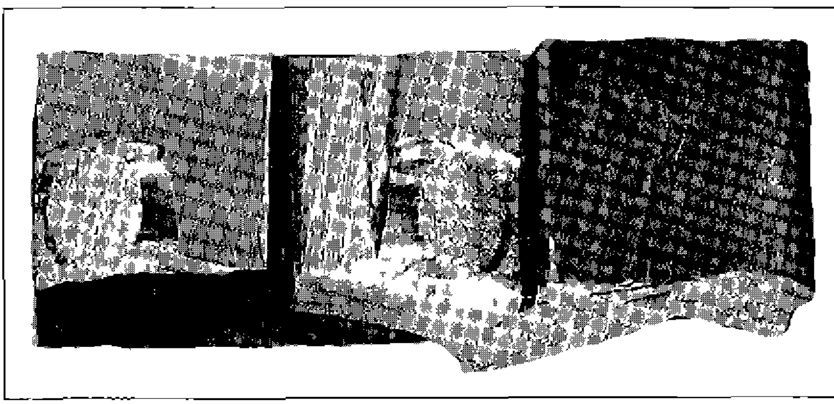

FIG 30b

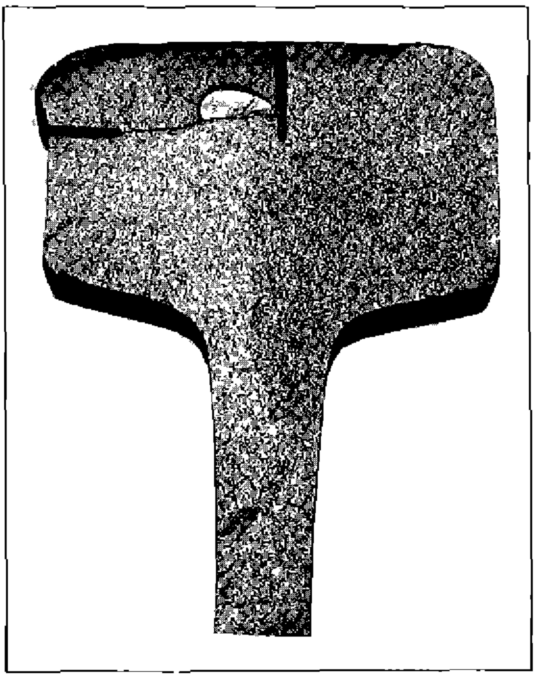

FIG 31*a*

FIGS 31*a* and 31*b* —Compound transverse fissure Horizontal split head branching upward into a transverse fissure Origin of split head at longitudinal seam

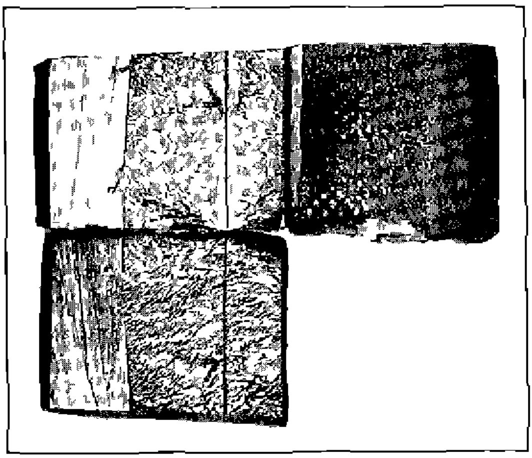

FIG 31b

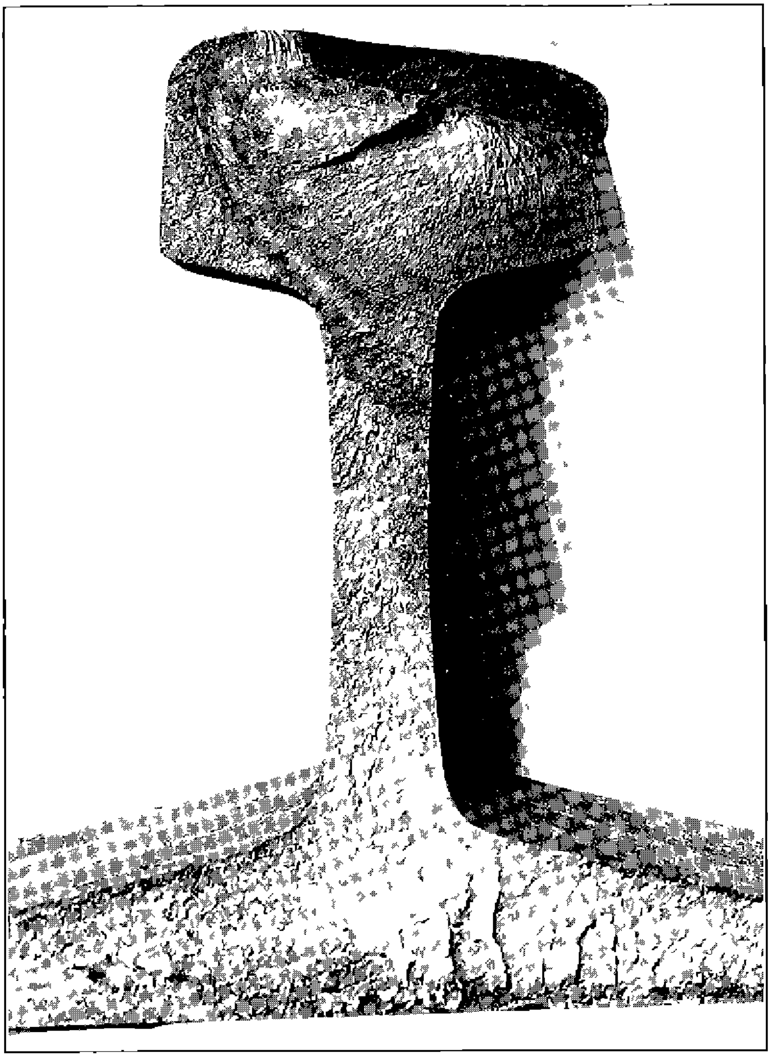

FIG. 32*a*

FIGS. 32*a* and 32*b*.—Compound transverse fissure in a 100-pound rail originating at a horizontal split head. Figure 32*a*, transverse fissure branching downward from split head. Figure 32*b*, two horizontal split-head cracks, the longer of which led to the formation of the transverse fissure.

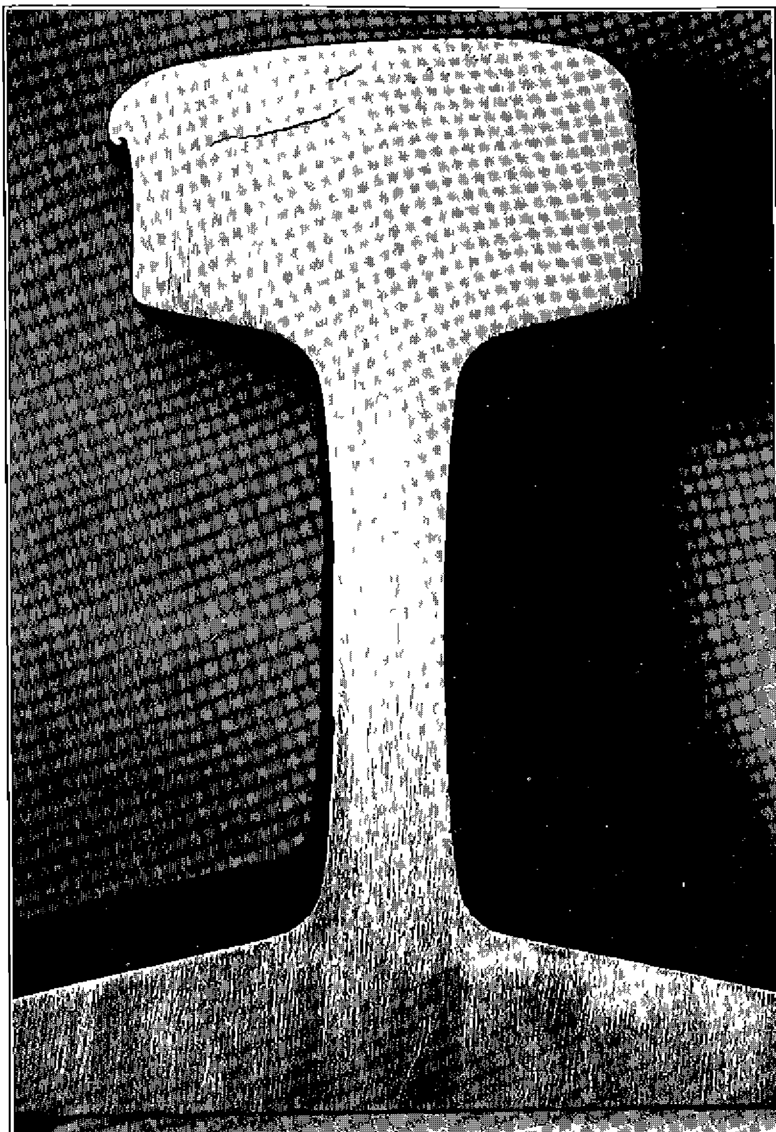

FIG. 32b

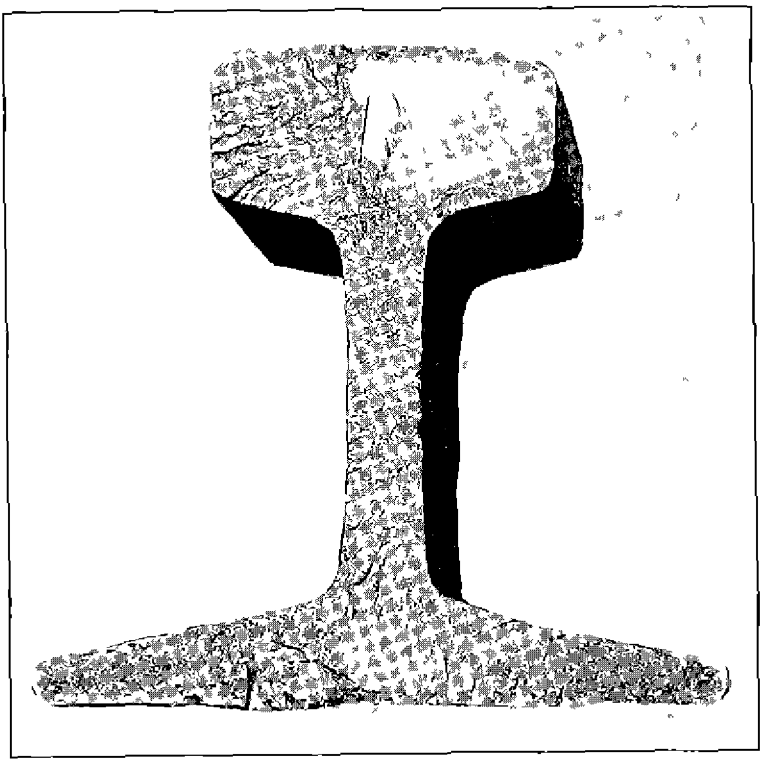

Fig. 33a.—Transverse fissure in an 85-pound rail arrested at a split head fracture.

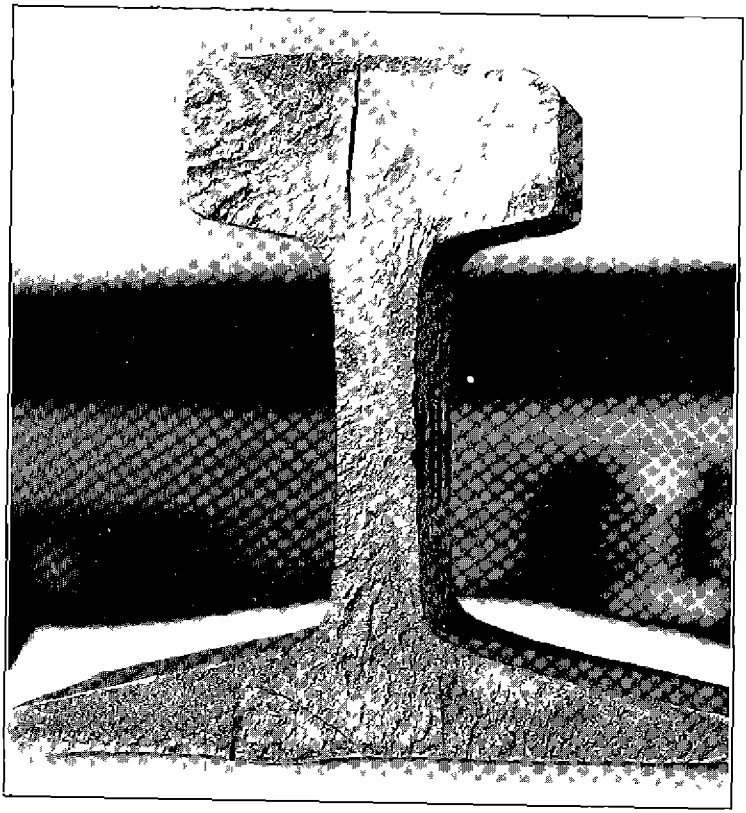

FIG 33b—Split head fracture of Figure 33a extended across transverse fissure by peening to running surface of head

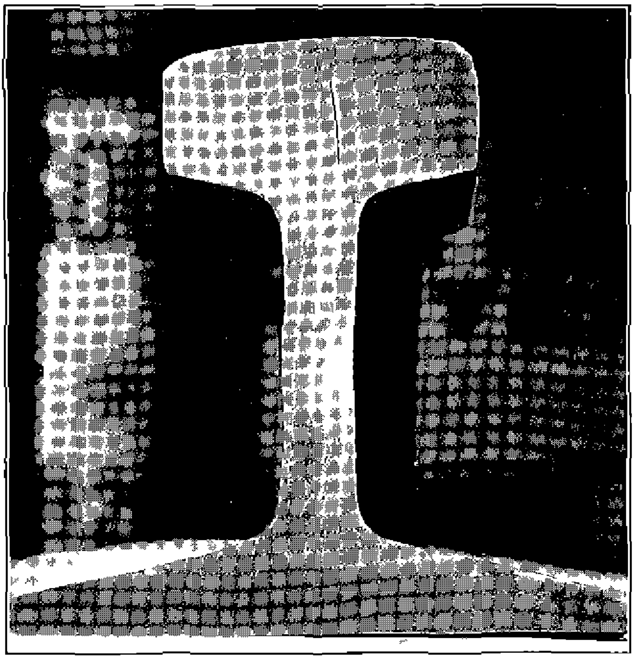

FIG 34a —Split head fracture in an 85 pound rail Opposite end of short fragment Figures 33a and 33b

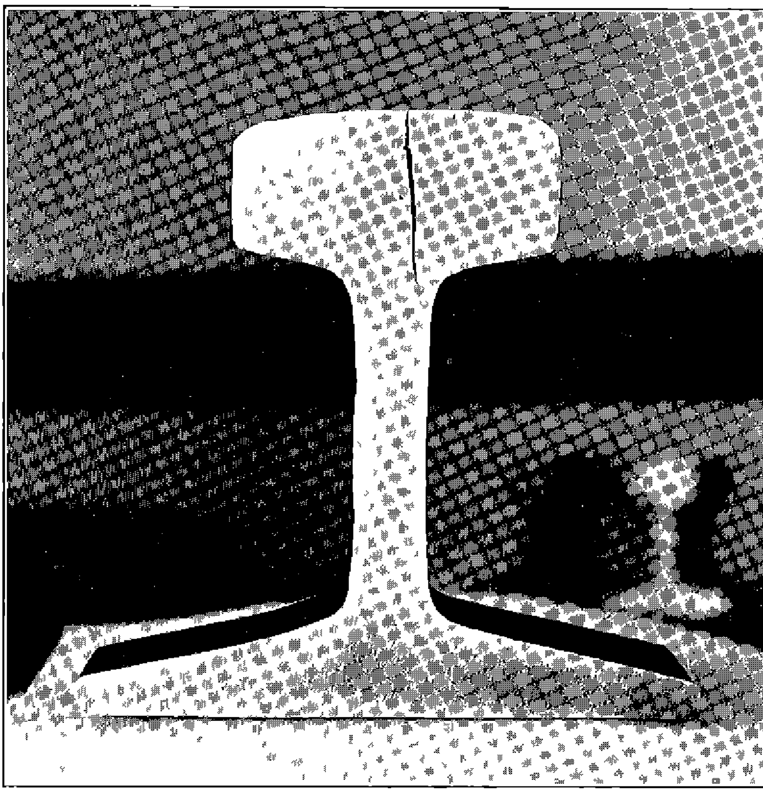

Fig. 34b.—Split head fracture of Figure 34a extended by peening to running surface of head.

MECHANICAL EXTENSION OF SPLIT HEAD FRACTURE

Figure No 34a represents the vertical crack in the head of the rail on the end opposite the transverse fissure which is shown by Figures No 33a After its further development the split head fracture is shown by Figures Nos 33b and 34b

The fracture of this rail illustrates the effects of two forces, a longitudinal force which developed the transverse fissure and a crosswise force which developed the split head Each for a time were probably developed independently of the other Cold-rolling effects are felt in two directions, setting up strains of compression both lengthwise and crosswise the rail It is unusual, however to find associated fractures of these two types

Perhaps these fractures were not of simultaneous origin, but when the transverse fissure had reached the middle of the head its progress was unquestionably arrested by the vertical crack The upper part of the transverse fissure then crept over its top

The split-head fracture extended in depth to a point abreast the filet under the head The upper part only is clearly shown by the cut This feature will be noted, that in the formation of the split head fracture the metal of the head was separated two thirds its depth without indications of its presence being presented on the running surface The usual dark streak along the middle of the running surface, so much relied upon as visible evidence, is an indication of a split head which comes late in its development When a dark streak becomes visible to the observer, the final stage of fracture is about reached The narrowness of this split head crack is again shown by Figure No 34a

After photographing, the split head fracture was extended by mechanical means analogous to the action of wheel pressures The top of the head was peened with a hand hammer setting up strains of compression which eventually were sufficient to cause an upward extension of the crack The peening was continued, along the middle of the length of this short section of rail, until the vertical crack reached the top of the head at each end of the specimen Figures Nos 33b and 34b show the results

The mechanically extended crack passed through the overlapping surface of the transverse fissure In the absence of longitudinal resistance the influence of the peening was felt only in a crosswise direction There is no reason for believing the extension of an incipient transverse fissure could not be accomplished in the same manner In fact it has been done with a small fragment of the head of a rail

One of the reasons why transverse fissures commonly develop into oval-shaped surfaces is the requirement that some portion of the cross section of the metal of the rail be in a state of compression to react upon and strain by tension the periphery of the transverse fissure The metal immediately below the running surface of the rail is virtually cold swaged, the grains of the steel flattened and, as well known, steel under such treatment will display greater ductility than possible in a tensile test where the total elongation has a relation to its tensile strength Malleability is the term which best expresses the ability of steel to flow under swaging pressures

External evidence of either a split head or a transverse fissure is presented only upon a close approach to final rupture A sag in the head means that longitudinal rupture along the fillet has nearly taken place, extending the fracture excepting a thin layer of metal below the running surface At that stage there is similarity in action between the shearing of a fin from the side of the head and detaching a major portion of the metal of the head The practical difference, however, is great in respect to the element of danger

In general, the actual separation of the surface metal of a split head rail first occurs in the fillet under the head, and the first visible surface separation of a transverse fissure is commonly on the side of the head or in the fillet

Figure No 35 illustrates the development of a transverse fissure in a 100-pound open-hearth Vanadium steel rail A large part of the cross section of the head had been fractured The transverse fissure reached the surface on the gauge side of the head, substantially its entire depth The fissure extended nearly across the width of the head but without reaching the running surface The feature of malleability preserved the metal from rupture at the immediate top of the head This rail displayed a transverse fissure after one year, 20 days' service

The presentation of a transverse fissure which covers so large a portion of the cross section of the head gives emphasis to the query concerning its rate of growth, whether uniform, accelerated, or retarded Under the present state of knowledge a definite answer can not be given A prognostication would depend upon complete knowledge of the forces which contribute to cause the fissure together with a consideration of the resistance of the rail at different stages in its growth

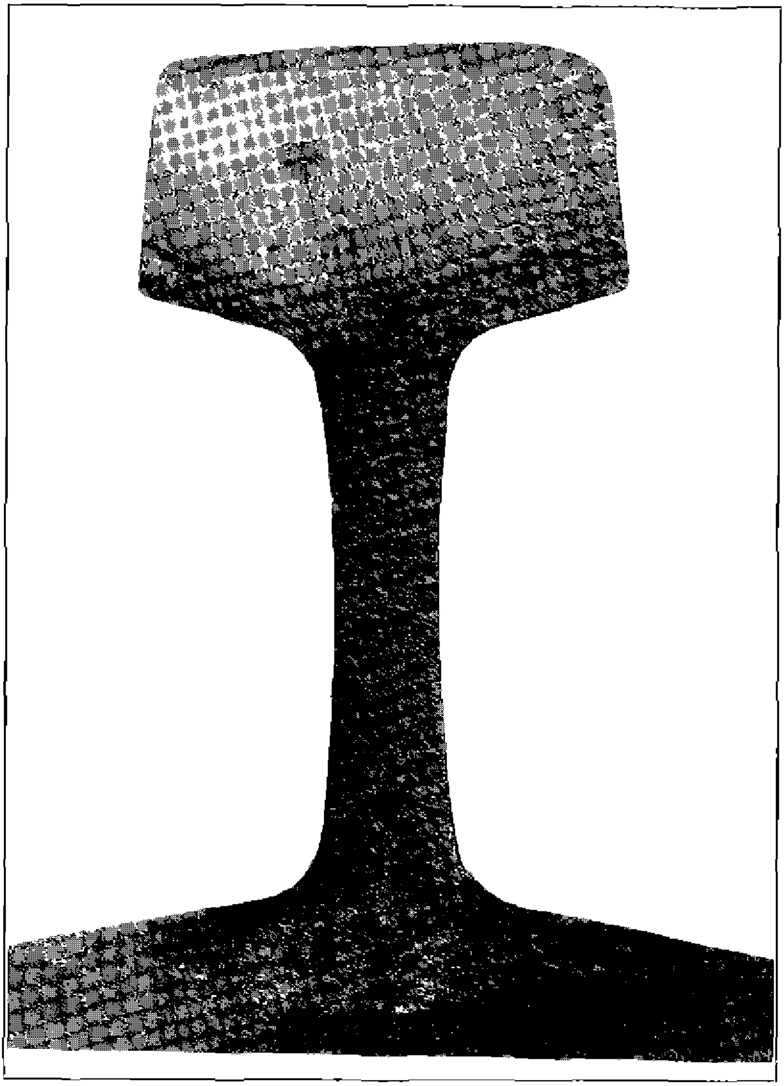

Fig. 35.—Transverse fissure in 100 pound O. H. Vanadium steel rail. Transverse fissure reached surface at side of head but not running surface.

BENDING STRESSES NOT PRINCIPAL FACTORS IN THE DISPLAY OF TRANSVERSE FISSURES

The properties of carbon steel are such that bending stresses can not be held accountable for the display of transverse fissures, except in a secondary degree As a beam the strength of the rail would rapidly diminish with the growth of a fissure The growth of two transverse fissures in close proximity would be practically incompatible with beam action When, however, a sufficient degree of weakness has taken place by reason of the extension of the transverse fissure the fracture of the balance of the rail suddenly occurs in the track, in the manner which it would fracture under a bending stress in the testing machine Since the rail sustained the bending stresses of the track while this weakening effect advanced it does not follow necessarily that final rupture occurred solely under the effects of bending loads

With so small an area of unruptured metal above the periphery of the transverse fissure, as displayed by the rail illustrated by Figure No 35, the completion of rupture does not admit of being attributed to the influence of the area of intact metal above the fissure Some recent results, which will be referred to later in this report, suggest the influence of longitudinal vibrations as a possible factor in the final fracture of transverse fissured rails

It has long been suspected that steel rails, not unlike metal located in other places would respond to the influence of vibratory waves Vertical waves are clearly apparent in the track, occurring under all speeds of trains Under transverse vibrations the outside fibers of the rails would be most affected, but these vibrations do not seem of greatest importance to fractures which develop from within the periphery In respect to longitudinal vibrations the matter presents a different aspect Heretofore in reports upon transverse fissures no reference has been made to vibratory strains, for the reason there was no evidence available associating such strains with the fractures of rails Evidence of such a nature has come to hand which will be incorporated herein

HEAD CHECKED RAILS

Figure No 36 illustrates a type of fracture in a 100-pound rail to which the name head check has been applied It originates at the surface of the head at or near the upper corner at the gauge side It develops in a transverse plane Originating in a locality where internal strains of compression are acquired some special reason for its inception must be present. It is apparently a type of wheel burning, in which strains of tension have been introduced.

A series of photomicrographs each 100 diameters magnification illustrate the appearance of the steel near the top surface of the rail, Nos. 36 a to f at places indicated by letters placed on cut No. 36. Figure No. 36a represents a longitudinal section, at the running surface of the rail, near the upper corner, gauge side. There was hardened and cracked surface metal, with a zone of hardened steel next below in which outlines of the grain structure remained. Figure No. 36b shows the depth of the hardened zone with the normal structure of the steel beyond. Nos. 36 a and b slightly overlap each other.

Figures Nos. 36c and 36d show the flattened grains of the steel near the upper outside corner of the head. Below a shallow layer of hardened metal the grains were flattened with an outward flow. These two are transverse sections. Figure No. 36e shows the distortion of the grain on a transverse section near the middle of the top of the head. Figure No. 36f, also a transverse section, shows the normal grain structure of the steel below the affected zones.

In respect to internal strains, relations have not been established between the zones of metal of normal shape and those of flattened grains. It has been found possible in the lathe, to turn off roughing chips from a steel axle of such depth of cut and feed that internal strains of tension resulted in the metal below the chips removed.

A thin layer of affected metal next the running surface was shown in early tests of steel rails. This layer of affected metal detracted from the bending properties of the rail leading to brittleness of fracture when loaded to extremity. Annealing restored the toughness of the rail. This behavior demonstrated the fact that the cold-rolling action of the wheels destroyed the toughness of the metal prior to actual rupture. In the physics of steel it is a matter of interest to know that destruction of toughness the ability to flow and take permanent sets, marks a stage in the approach to rupture prior to the actual separation of elementary parts.

This phenomenon appears to be witnessed in high manganese steel rails, leading to progressive fractures beginning at the running surface of the rail and extending downward through the head and into the web.

Figure No. 37 illustrates the gashes which were formed in the head of a high manganese steel rail in a bending test, with the head on the tension side. Fractures of this kind are not displayed by carbon-steel rails. The toughness of this remarkable material was destroyed by the cold rolling of the wheels at the immediate running surface

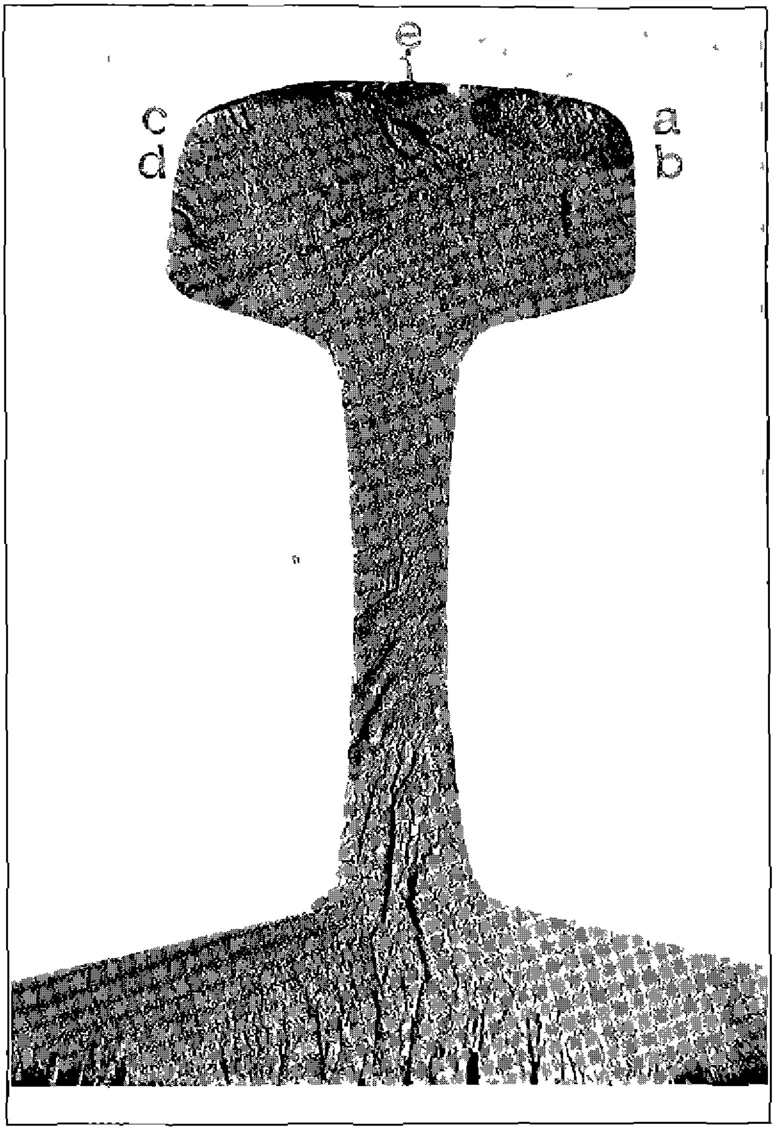

FIG. 36.—Head checked rail. Weight 100 pounds per yard. Microstructure shown by Figures No. 36 *a*, *b*, *c*, *d*, *e*, and *f*.

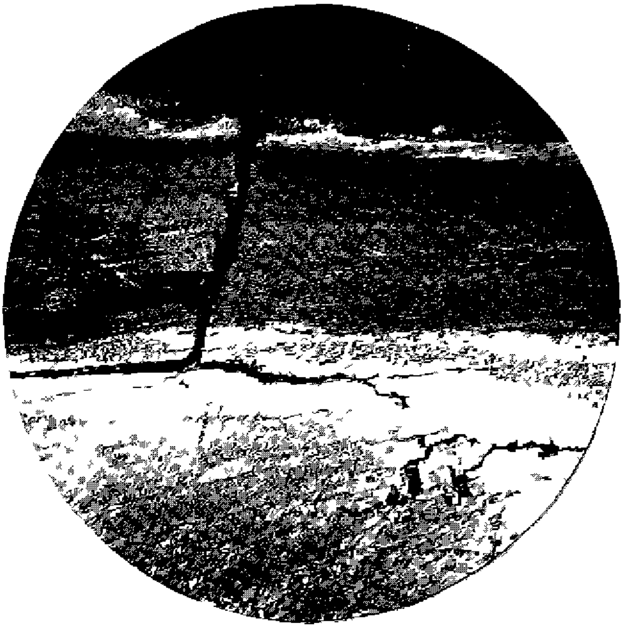

FIG. 36a

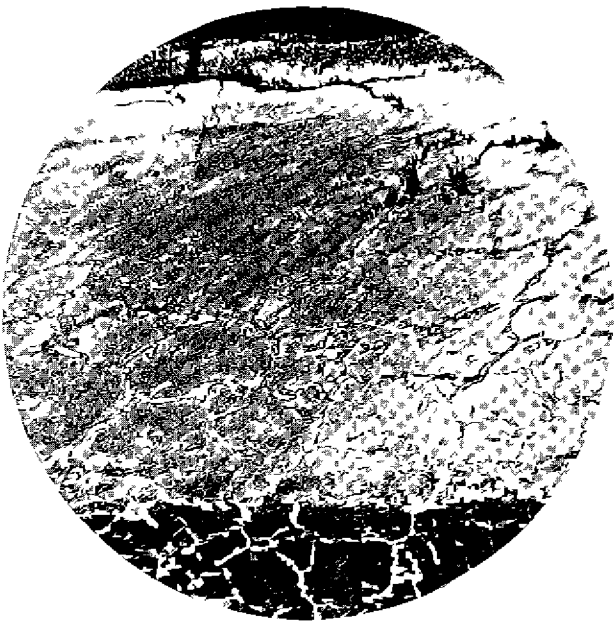

FIG. 36b

FIG. 36a.—Microstructure at *a*. Hardened and cracked surface metal and hardened metal next below with outlines remaining of grain structure. Longitudinal section. Magnification 100 diameters.

FIG. 36b.—Microstructure next below 36*a*. Hardened zone with normal structure below. Sharp line of demarkation. Longitudinal section. Magnification 100 diameters.

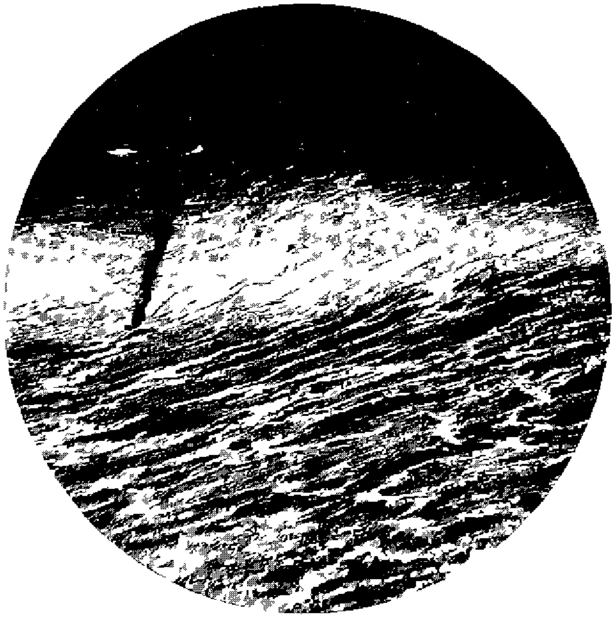

FIG 36c

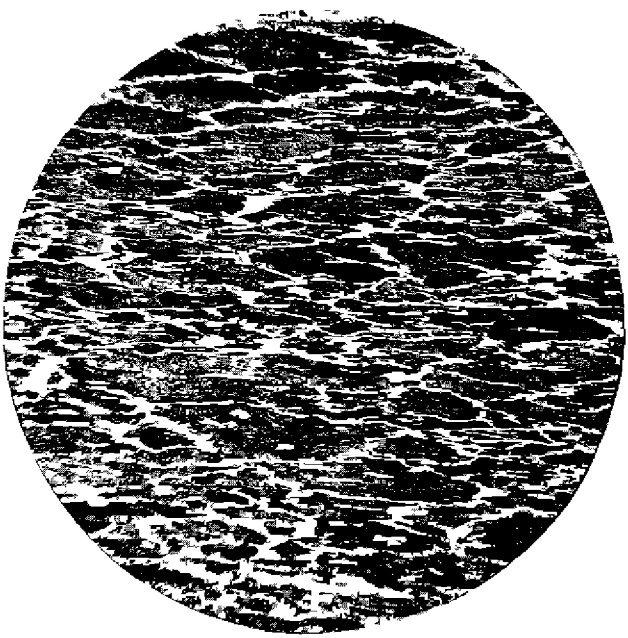

FIG 36d

FIG 36c—Microstructure at c at running surface Hardened skin and flattening of the grains showing outward flow Transverse section Magnification 100 diameters

FIG 36d—Microstructure below 36b, near outside corner of the head, showing flattening of the grain with outward flow Transverse section Magnification 100 diameters

Fig. 36e

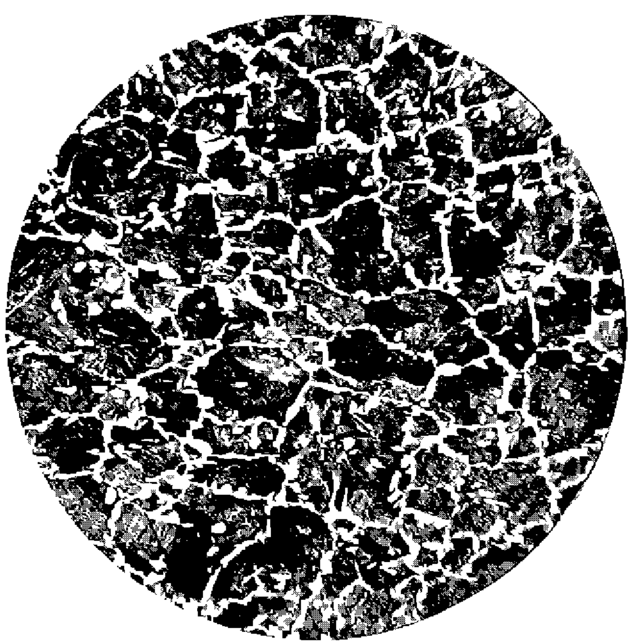

Fig. 36f

Fig. 36e.—Microstructure near top of head, middle of width. Slight hardening of the surface metal and shallow zone of flattened grain. Transverse section. Magnification 100 diameters.
Fig. 36f.—Normal structure of the steel. Vicinity of upper part of head. Transverse section. Magnification 100 diameters.

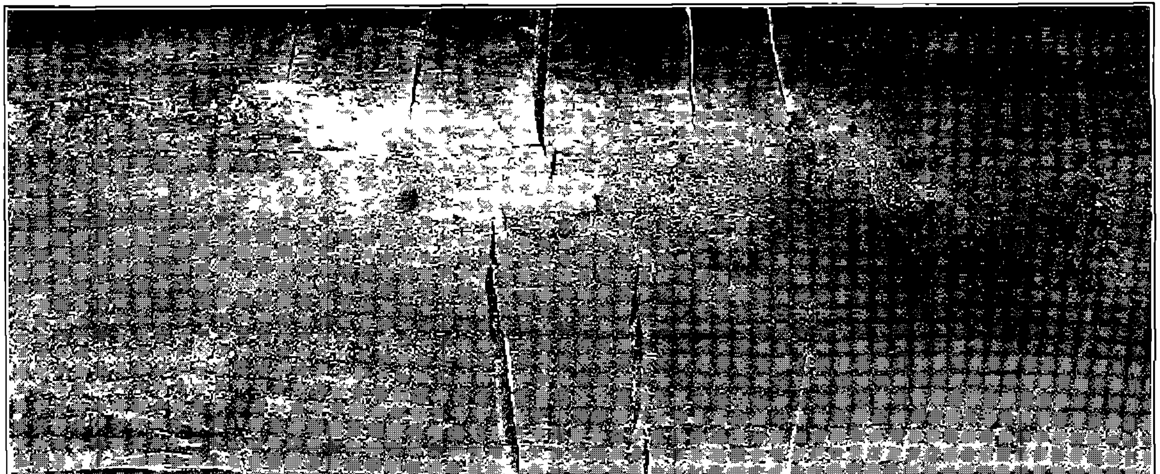

FIG. 37.—Manganese steel rail 100 pounds weight per yard. Cracks in running surface developed in a bending test of the rail. Elastic limit approximately 54 000 pounds per square inch.

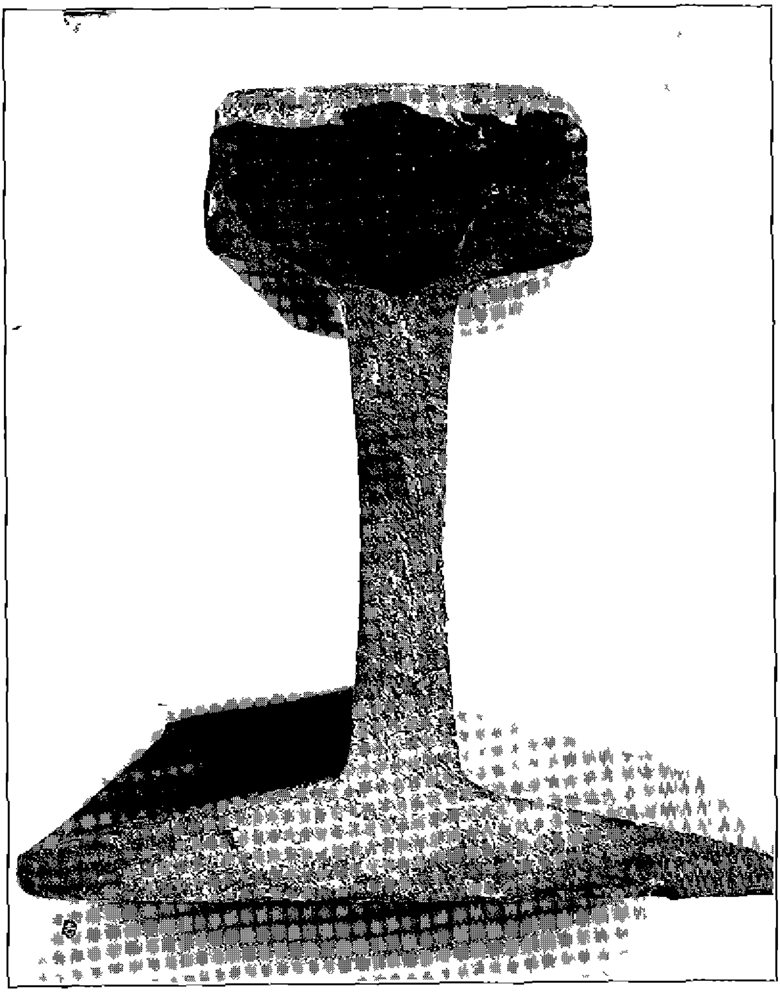

FIG. 38.—Transverse fissure displayed by a medium manganese steel rail. Bessemer steel. In service 13 years.

The toughness of the steel below the affected zone was retained and the extensions of these gashes restricted In this feature the behavior of high manganese steel is unique It possesses elements of safety against sudden rupture witnessed in no other steel

Favorable reports have been announced concerning the resistance of rails of medium manganese content against the formation of transverse fissures, manganese of 1 25 to 1 75 per cent Investigation of the properties of this grade of steel have shown it not unlike carbon steels, so far as laboratory tests indicate

TRANSVERSE FISSURE IN MEDIUM MANGANESE STEEL RAIL

Figure No 38 illustrates the appearance of a transverse fissure displayed by a rail of medium manganese content This was a Bessemer steel rail, 100 pounds weight per yard, which had been in service 13 years Chemical analysis made of the metal from the top of the head gave the following results C 0 61, Mn 1 23, P 0 059, S 0 153, Si 0 142

The transverse fissure was located 9 feet 8 inches from the receiving end The middle part of the length 11 feet 4 inches, was broken into 56 pieces The leaving end remained intact

The circumstance of this being a Bessemer rail does not present an unusual feature In a compilation of transverse fissured rails 698 Bessemer steel rails came to notice

WHEEL BURNT RAILS

Wheel burnt rails are of common occurrence, every yard furnishing examples They are specially prevalent wherever trains stop and start The cause of their occurrence is the skidding of the wheels, their rotation being either faster or slower than the movement of the train, it is immaterial which Some examples are pronounced by reason of the severity of their appearance, exhibiting deeply serrated and roughened surfaces of the heads of the rails while others hardly display any of these familiar manifestations Wheel burning also appears in situations where it would not ordinarily be expected

The frictional resistance encountered in the slipping of the wheels raises the temperature of the surface metal of the rail practically instantaneously Frictional resistance is doubtless the most expeditious method of raising the temperature of steel to an incandescent heat When heated suddenly and of short duration only a superficial layer of the metal is directly affected By conductivity the metal next below quenches the intensely heated surface metal In steels having the chemical composition of rails this sudden abstraction of heat effects thermal hardness of the metal. Similar effects are witnessed at the ends of cold-sawed rails.

In the microscopic examination of wheel-burnt rails, layers of hardened steel are found superimposed on metal of normal structure. Examples have also been witnessed in which the immediate surface metal had evidently been reheated and annealed. Those examples displayed an upper layer of annealed metal resting upon a hardened layer, which in turn rested upon metal of normal structural state. Different results will be reached according to the rate of heating, the degree of temperature reached, its duration, and the rate of cooling.

The usual appearance of a wheel-burnt rail requires no illustration. However, a better conception of the disturbed metal may be obtained by pickling in hot acid. Pickling may even reveal the presence of wheel-burnt metal not apparent when the rail was in the track. Flange-worn rails have exhibited such evidence. Rails have shown a series of thermal cracks, on the corner of the head, gauge side, of such regularity of spacing they resembled the graduations on a foot rule. Such thermal cracks have been witnessed on the low rails of a 3-degree curve.

In skidding, the wheels should not remain long in one spot to effect the hardening of the surface metal. Prolonged heating, due to the slipping of wheels without their advance, raises the general temperature of the entire head, with results entirely different from those which follow sudden heating and cooling. A very complex state of internal strain is set up by prolonged heating, depending upon conditions which fluctuate so widely that no accurate prediction can be made of what the final results will be.

An example of prolonged heating was presented in the wheel burning of some 90-pound rails which were located in a tunnel. The wheels skidded for a time before it was realized the engine was not in motion. The tops of the heads of the rails were hollowed to a depth of 0.3 inch under the wheels. The entire heads and a portion of webs were heated red hot.

The internal strains in one of the rails were measured. At a stage in the examination of the rail the internal strains taken along one element of the head represented a stress of 16,200 pounds per square inch tension, while at another stage the stress along the same element represented 14,100 pounds per square inch compression. Planing away a portion of the cross section of the rail reversed the internal strains along the measured element.

Notwithstanding the structural injury ordinarily caused by wheel burning the injured zones are reenforced and held together so efficiently, by virtue of the physical properties of the steel, that the rails are enabled to endure this severe treatment and remain intact and serviceable, at least in many cases Rails which have fractured from this cause, which is also called snow burning in some sections of the country since such occurrences take place while ploughing out snowdrifts, have exhibited great local disturbance of the metal before they succumbed to these destructive influences

BOLT-HOLE FRACTURES

Whenever steel is exposed to alternate stresses and of sufficient intensity the ability to permanently elongate under tensile stress is destroyed Conditions at the walls of bolt holes in rails are such that loss of ductility is there experienced The drilling of bolt holes, adopted many years ago to escape the objections to punching, does not eliminate the danger of rupture under service conditions

Rails display brittleness of fracture at bolt holes Fractures originate at their walls without appreciable enlargement of their diameters This happens while the metal at adjacent bolt holes may still retain its ability to be drifted into much larger holes without rupture The brittleness displayed is attributed, in part at least, to hammer action between the webs of the rails and the shanks of the track bolts Clearance originally provided for is lost by the creeping of the rails Bolts are frequently bent and the walls of the bolt holes are upset

Some fractures take longitudinal courses across the horizontal diameters of the bolt holes, others form on oblique lines at angles 45° with the longitudinal axis of the rail The display of oblique lines of rupture is taken to indicate that shearing stresses play a part in the formation of bolt-hole fractures

The presence of this type of fracture is obscured in its early stages by the splice bars Not until a fracture has extended beyond their ends does it commonly admit of detection In some cases a horizontal line of rupture bifurcates and completely detaches a short piece of the rail or separates a piece of the head from the web and base

ARTIFICIAL TRANSVERSE FISSURES

Transverse fissures have been produced experimentally in new rails Their positions in the head of the rail was under control They were developed centrally when the rail was loaded in upright position, or located in the right or left side of the head when the rail was canted to the right or to the left

Artificial transverse fissures were made by means of gagging blows applied successively at short intervals along the head, then reversing the rail and repeating the blows along the base The tests were made on half-rail lengths Referred to full-rail lengths, the number of blows required to break the rails and disclose the transverse fissures ranged from 50,000 to 250,000 Each gagging blow was more severe than used in the ordinary straightening of a rail These tests showed there is little need of anxiety concerning the effect of a score or less of gagging blows in the usual straightening in the gagging press as affecting the integrity of the metal Gagging blows in ordinary practice are delivered only once or twice in a place, and seldom in reversed direction

In producing artificial transverse fissures it was necessary to gag the rails successively at short intervals along their lengths, reproducing as nearly as possible track conditions of continuous rolling by the wheels Gagging in the same plane alternately on the head and the base resulted in regular beam fractures, that is, in fractures having their origins in the outside fibers of the rails

Artificial transverse fissures were of interior origin, identical with those developed in the track They displayed surfaces resembling the nuclei of track transverse fissures, without the silvery burnished effect believed to be caused by the opposite surfaces being hammered together and closing the minute gap between them when the wheels are directly above them

Different weights of rails and different heats of steel were represented in these artificial transverse fissures

TRANSVERSE FISSURES IN SEVERAL PLACES IN THE SAME RAIL

Certain rails contain only one transverse fissure when they are removed from the track for the display of this type of fracture In others several fissures exist in different stages of development Among those which have been examined many have been found to contain more than one fissure The transverse fissure displayed in the track is commonly a pronounced one in respect to size but not always the largest in the rail

Figures Nos 39 *a*, *b*, and *c* illustrate the fractured surfaces of a rail which was broken, after removal from the track, in 15 places At 11 places transverse fissures were in the process of development Starring effect, so called, characterized four of the fractured surfaces

In this group the fracture which was made at the distance of 28 feet 1 inch from the leaving end of the rail displayed a minute silvery crescent This manifestation identifies the fracture as an incipient transverse fissure The nuclei of transverse fissures present characteristics shown in tensile fractures and likewise those of shrinkage cracks The identity of an incipient transverse fissure becomes certain only when evidence is presented of its progressive formation, that is, when a silvery luster is shown on a portion of the fractured surface

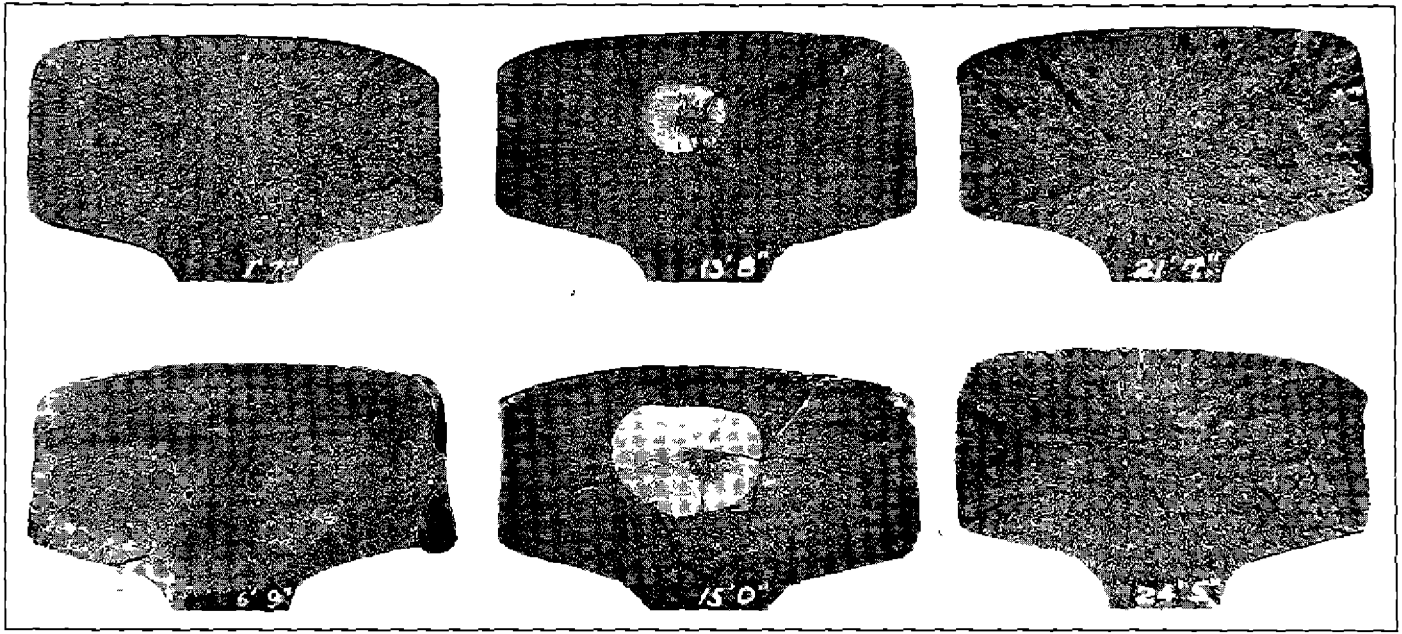

FIG 39a.—Stalling effects and transverse fissures in different stages of development in a 90 pound rail Fifteen fractured surfaces

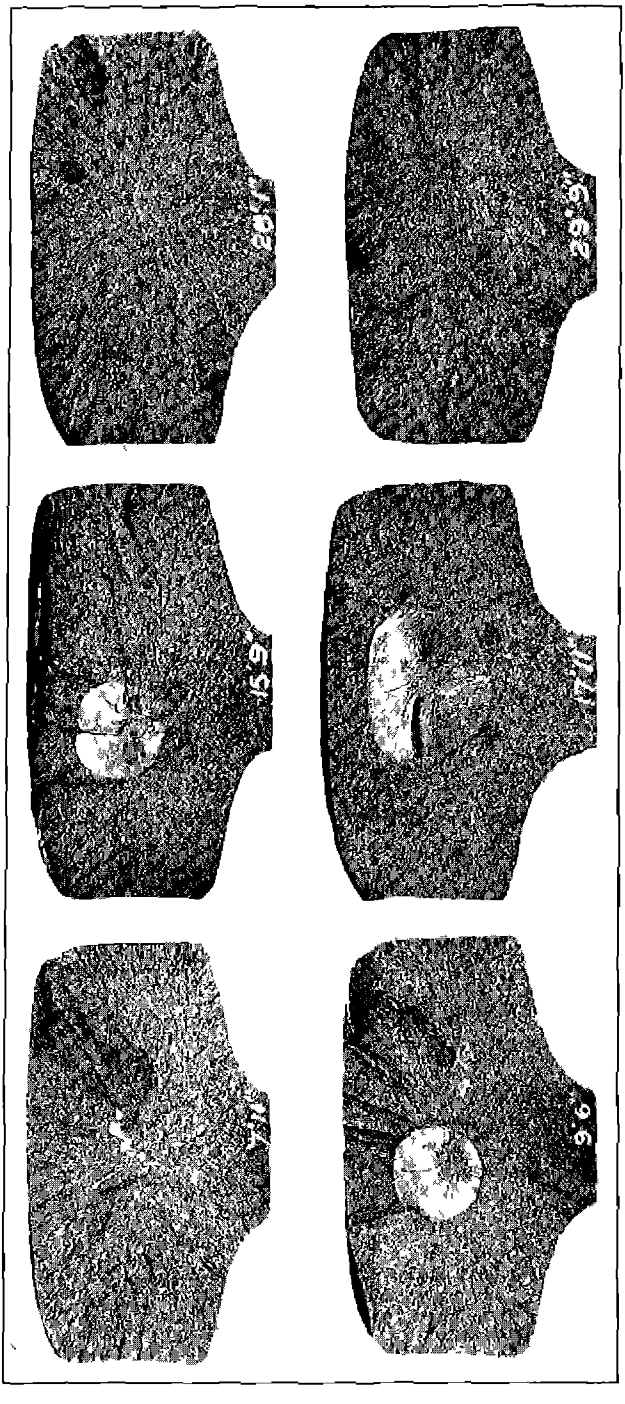

Fig 39b —Starring effects and transverse fissures in different stages of development in a 90 pound rail Fifteen fractured surfaces

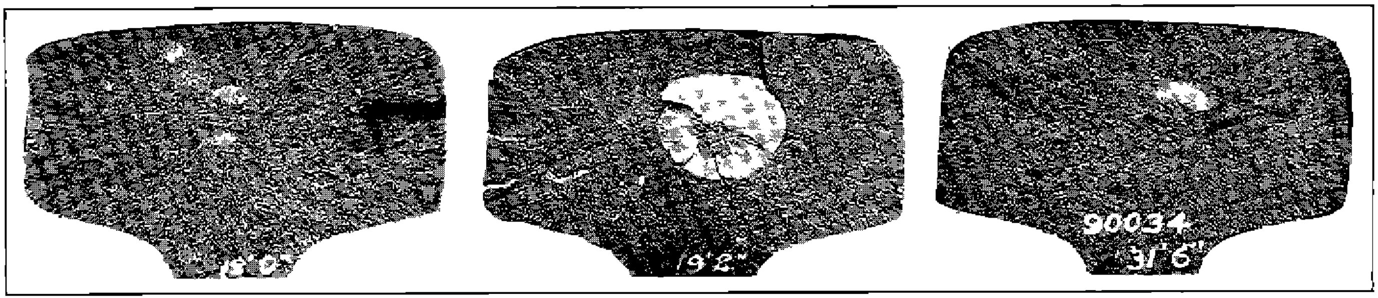

FIG. 39c.—Starring effects and transverse fissures in different stages of development in a 90 pound rail. Fifteen fractured surfaces.

When a rail is broken under the drop with the head in tension a starring effect of interior location is commonly shown This does not mean necessarily that the locus of a transverse fissure has been displayed It identifies the point where the metal first separated Before rupture occurred the metal at that place, some distance from the neutral axis of the rail, may have elongated several per cent The difference in behavior will be kept in mind between the measurable elongation of the metal in a rail fractured by a bending test and the absence of measurable elongation in the case of a transverse fissure Erroneous interpretations of what has been witnessed would account for the early announcements made upon the presence of embryonic transverse fissures in new rails

Figure No 40 is a line drawing showing the locations and diameters of 50 transverse fissures which were found in the same rail One transverse fissure was displayed in the track, one in handling, and 48 others in its subsequent test under the drop Some of the short fragments, the subjects of later studies, displayed additional fissures

This was a 90-pound rail, which had been in the track for a period of 14 years The mill analysis for the heat was C 0 72, Mn 0 75, P 0 033, S 0 036, Si 0 20 It had the ingot letter E or F Examination showed a shattered core in the center of the head, in which zone at least some of the transverse fissures had their origins There was no abnormality in microstructure nor foreign inclusions associated with any of the fissures examined The aggregate area of the fifty-odd transverse fissures was four times the entire sectional area of the rail

TRANSVERSE FISSURES DISCLOSED BY SHOCK TESTS

In cutting rails to length in the reclamation yard of the St Louis-San Francisco Railroad, Mr J G Taylor, special engineer effects rupture by endwise shocks Starting a crack in the rail by nicking with a chisel, rupture is completed by striking the end of the rail with a sledge hammer The longitudinal vibrations set up by the shock of the hammer are adequate to complete the fracture of the rail, an exterior crack of limited extent having been made by the chisel

Shock tests were made upon a section of a rail which displayed a transverse fissure in the tracks of the Chicago & North Western Railroad This was a Gary rail rolled in October, 1912, weighing 100 pounds per yard The section experimented upon was 9 feet 10 inches long, one end of which was hot sawed, the other end had a transverse fissure, 1½ inches in diameter, displayed in the track

There were surface indications of two additional transverse fissures in this section, which approached very near the periphery of the head The section was therefore an eligible one upon which to repeat

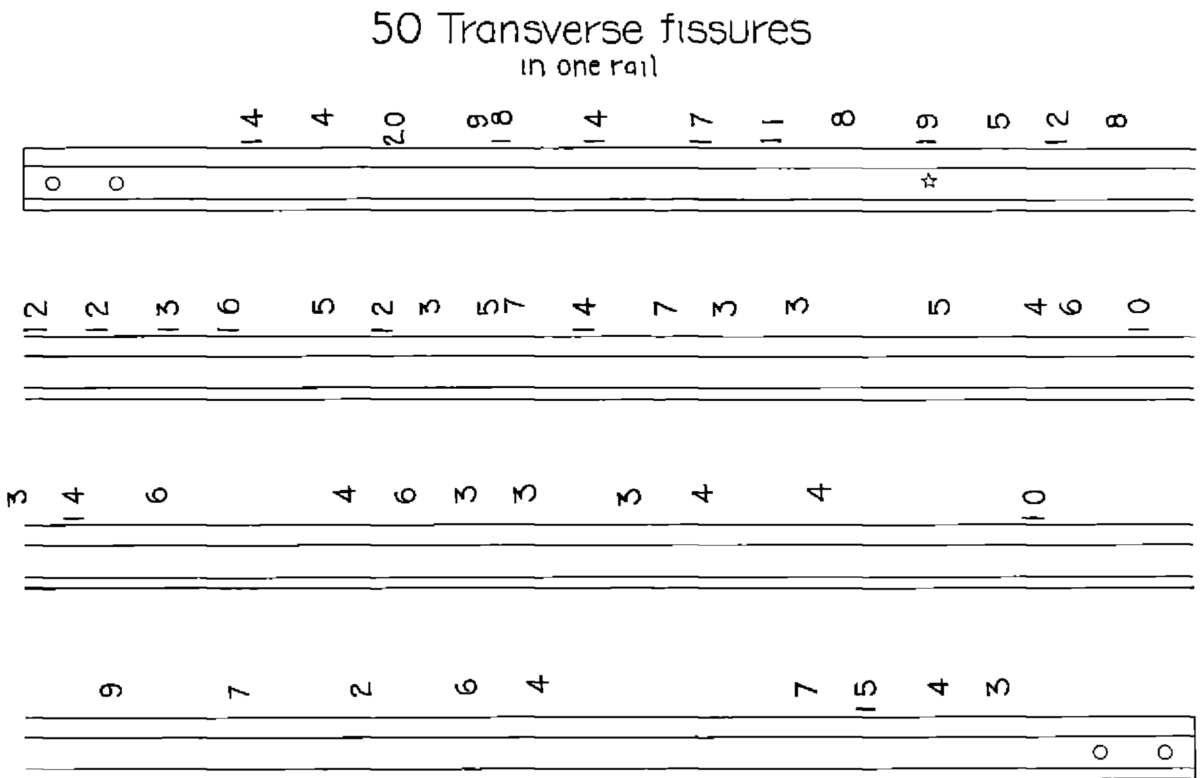

FIG. 40.—Fifty transverse fissures in the same rail. Ninety pound rail about 14 years in service.

the shock test of the St Louis-San Francisco Railroad There was a third transverse fissure in this section of rail the presence of which was unsuspected, but which the shock test disclosed

The hot sawed end of the rail was struck with a 10-pound sledge about 20 sharp blows, whereupon the rail separated near the middle of its length at a transverse fissure having a diameter of 1½ inches The surfaces were bright and silvery

Resuming the test, a few additional blows of the sledge caused the rail to separate at a transverse fissure located 20 inches from the hot sawed end It had a diameter of 1¾ inches, the surfaces being bright and silvery There were no surface indications of the existence of this transverse fissure prior to the shock test

Again testing one of the longer fragments, two blows of the sledge caused the rail to separate at a transverse fissure located 15 inches from the fissure which was displayed in the track The surfaces of this fissure were also bright and silvery

Thus, it happened that three transverse fissures were displayed in this piece of rail by means of endwise shock, striking the rail on end with a 10-pound sledge

In the second test there was a noticeable change in the pitch of the note emitted by the rail after a few blows of the sledge Before rupture was completed the pitch of the note was much flattened, clearly indicating progressive fracture under the vibratory strains

The longitudinal vibrations, concentrated and intensified at the edge of the interior fissures, caused rupture which under conditions of static load would have required several hundred thousand pounds gross stress These transverse fissures each comprised about 20 per cent, the full sectional area of the rail or 40 per cent the sectional area of the head

Certain longitudinal strains would be expected to accompany the vertical wave motions experienced in the track, and become factors in promoting rupture Indeed the presence and influence of longitudinal vibratory strains seems essential to aid in reaching final rupture when the area of unruptured metal above the transverse fissure has become much reduced Upon such an hypothesis high speeds would become active factors in the development of transverse fissures

In ordnance engineering it is held that longitudinal wave motions traverse the chase of a gun in advance of the projectile and are reflected in such a manner that the normal radial strains from the powder pressures are increased At high rates of speed a wheel traverses the length of a rail in about one-third of a second of time, a rapid movement but not comparable to the rate of travel of longitudinal vibrations in steel It is conceivable that high speeds, as well as intense impinging wheel pressures, each contribute their share toward the development of transverse fissures, and that bending stresses in a rail which sufficiently weakened may share in its final rupture

THE DETECTION OF PARTIALLY DEVELOPED TRANSVERSE FISSURES

Transverse fissures in the tracks before final separation of the rails are at times discovered Fine hair lines appear on the side of the head, commonly on the gauge side, where vertical cracks separate the peripheral metal Prior to complete separation a rust streak may appear, indicating the approach of a transverse fissure to the surface of the head Careful scrutiny is necessary to detect these premonitory signs which do not appear until complete fracture is close at hand Some surface manifestation is, of course, necessary to admit of macroscopic detection

When thousands of rails each year display transverse fissures it is a matter of grave importance respecting safety of travel to acquire some definite information upon their presence in rails in the track in their early stages of development Derailments due to transverse fissures are rare in which the initial break in the rail does not show a fissure having darkened surfaces, that is, a transverse fissure which had not broken through the peripheral surface of the head, admitting air and acquiring darkened surfaces It follows that all such fractures were possible of detection before the derailment occurred The possibility of detection, however, may have been limited to an interval of time of very brief duration, too short to be of practical value There are physical limits to track inspection, and the detection of rails which are on the immediate verge of rupture yields a margin in safety too slender to commend itself

It is customary on some railroads to remove from the track all rails of a heat in which a certain number have displayed transverse fissures Under the rules established by one State such removal is mandatory when three rails have displayed transverse fissures The promulgation of such a rule carries with it, by implication, the assumption that some inherent defects exist which permeate the entire heat The physical condition of the rails thus removed, however, does not appear yet to have been the subject of inquiry From the standpoint of economy it is not justifiable to remove thousands of rails upon unsupported suspicion By implication, also, such rules place responsibility for the display of transverse fissures upon some indefinite, undefined property of an entire heat upon which no evidence has yet been discovered Some inspecting engineers go a step farther and assume that individual ingots differ essentially in their tendencies to display transverse fissures Vagueness prevails in the foundations of such beliefs, which attach to no known physical property. The only definite feature is the assertion itself that some heats of steel display transverse fissures while others do not, or have not under identical conditions of service.

The detection of the presence of transverse fissures in their early stages of development presents a tangible subject for discussion. Devices which have been offered are of two classes, those which depend upon variations in magnetic properties and those which depend upon differences in electrical resistance. No practical results appear to have been reached with magnetic devices, and contingencies are such that none would seem to be expected. Nearly 50 years ago extravagant expectations attached to the subject of magnetic testing which subsequent information indicated was fallacious.

The possibilties of an electrical resistance method was definitely shown in a demonstration made by Mr. Elmer A. Sperry in the year 1923 or early part of 1924. Experiments were conducted upon a model in which an interior air gap had been prepared, representing in effect a transverse fissure. The location of the air gap was indicated by Mr. Sperry's device, who at that time expressed the conservative belief that an internal transverse fissure equal in area to 15 per cent of the head could be detected by his apparatus.

Since no transverse fissure of that limited size has come to notice as the primary cause of a derailment it necessarily followed that the detection of such fissures in the track and those somewhat larger in size would be the means of averting accidents due to the development of this type of fracture.

It then definitely appeared that a device had been presented for the first time which made it possible to detect in rails in service this most insidious and dangerous type of fracture. Such a device opened great possibilities, marking a most important advance in research work and achieving success in a line of work directly associated with safety in travel.

The results of the demonstration made by Mr. Sperry in 1923 did not immediately attract favorable attention from the users of rails. However, after the lapse of some three years the matter was taken up officially by the users of rails and an appropriation made for the fabrication of an apparatus for the tests of full-sized rails.

THE SPERRY ELECTRICAL RESISTANCE AMPLIFYING TRANSVERSE FISSURE DETECTOR

The honor of devising an apparatus capable of detecting the presence of danger lurking within the head of a rail was thus reserved for Mr. Elmer A. Sperry. Among safety appliances its position is unique Safety in travel is menaced by a type of fracture which develops in the heads of rails, to which the terminology transverse fissure has been applied It is a hidden danger Other safety appliances deal with visible elements of danger, this with unseen danger

Recent demonstrations with the Sperry detector have shown it capable of indicating the locations of transverse fissures in different stages of development from those in area less than 2 per cent the area of the head up to those which have separated the major part of its cross section Conversely, certain rails each of which has displayed a transverse fissure in the track and have been shown by the detector to contain none other, the most diligent search for an additional fissure has been without avail The detector differentiates the interior fissures according to their sizes

The Sperry detector opens the way for the acquisition of accurate information upon the structural state of steel rails not realized in any other device yet presented In addition to locating transverse fissures in rails in the track, the detector is, of course, available for the examination of rails of heats which have been removed from the track on suspicion of containing incipient fissures Furthermore the detector would be serviceable in the examination of rails heat treated to ascertain whether such rails had interior cracks oriented after the manner of transverse fissures or contained shrinkage cracks of magnitude

The Sperry detector signalizes the most important step forward—in fact, the only one of its kind—during the period of 16 years since this type of rail fracture came into prominent notice

ORIGINS OF CERTAIN FRACTURES IN RAILS UNDER DROP TESTS

Reference has been made to the proper reading or interpretation of fractured surfaces The first consideration which should be given fractured material is to note the location of the origin of fracture and trace the direction in which the line of rupture progressed Explanations which account for the fracture of a rail must be in harmony with the evidence presented by the fractured surfaces The ease with which fractured surfaces may be read should be familiar to all whose duties connect them with such occurrences

Steel fractures usually have their origins defined by easily recognized nuclei, from which emanate radiant lines The name "starring" has been given such appearances The extension of a line of rupture along a narrow section of metal is illustrated by a fanlike appearance

Steel rails broken by bending tests or under the drop commonly show the exact points at which the fractures had their origins

Rails struck on the head with the falling tup of the drop test are expected to have the origins of their fractures located in some part of the base, and when broken in reverse direction to have their origins in the head. Fractures do not always originate in the most remote fibers from the neutral axis of the rail. In new rails their origins are seldom in the most remote fibers.

Slightly decarburized surfaces increase the toughness of the outside fibers and lead to fractures of interior origins. Abrupt changes in cross-section dimensions lead to fractures having their origins at the fillets of the web, especially in rails of the heavier sections. Dog marks in the web have located incipient points of rupture. A slight chisel nick in a flange will lead to rupture starting from the nick. Dropping the wheels of a hand car and indenting a flange will lead to the same result. Small holes for bond wires inadvertently drilled in the flange will lead to the fracture of the rail. A change in structure of the steel accompanied by the introduction of internal strains such as the brazing of bond wires at the junction of the web and the base will lead to rupture under service conditions, some of these features having been previously referred to.

Figures Nos. 41 and 42 show the location of fractures of some rails which were broken under the drop. Stars placed on the cuts above or below the origins of the fractures indicate the locations of the incipient points of rupture. The starring effects in the heads of two rails are illustrated by Figure No. 41, one of which is eccentric, the other at the center of the head. Transverse fissures might, in the course of time, start at each of such places. It would be erroneous, however, to designate these as incipient fissures. A silvery crescent or silvery oval identifies a transverse fissure. The initial separation of the metal at a transverse fissure presents the same appearance as the initial point of separation of a tensile test piece. At their periods of inception tensile test pieces and transverse fissures are necessarily alike, each being a tensile fracture. Shrinkage cracks are also tensile fractures.

Figure No. 41 illustrates starring effects in the bases of two rails, and a portion of the surface of a third rail the fracture of which originated under the head. One of the base fractures was eccentric with reference to the web, and at the middle of the depth of the flange at that place. The other base fracture originated at the middle of the width of the base, at its lower surface.

Arrows indicate the directions in which the several fractures traversed the cross sections of the rails. The cuts do not clearly show the characteristics of the fractured surfaces which on the rails themselves were very pronounced.

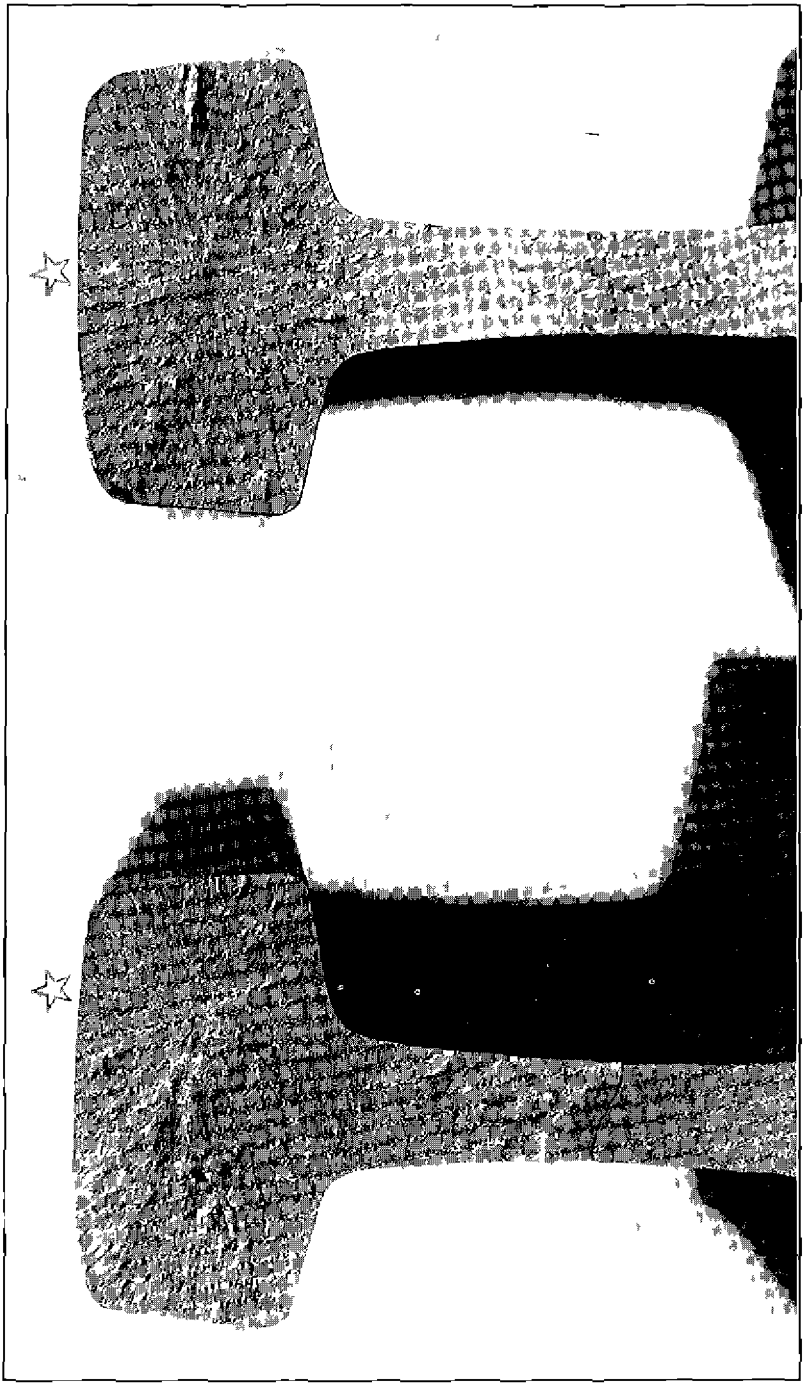

Fig 41 —Starring effects in the heads of two rails

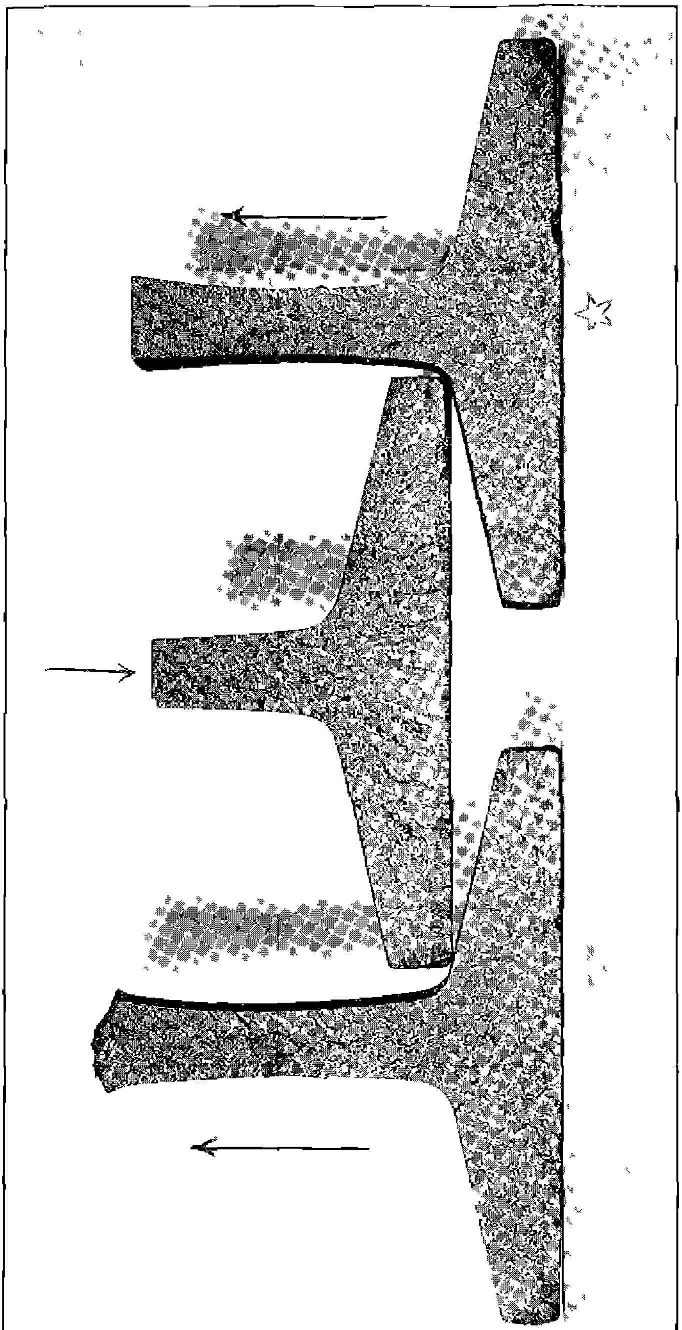

Fig 42 —Starring effects in the bases of two rails Fracture of third section originated under the head Arrows indicate the directions the lines of rupture followed

A FEW NOTES ON THE FABRICATION OF STEEL RAILS

Critical comments appear from time to time upon mill practice including both the making of the steel and the rolling of the rails The trend of such comments has been to place the responsibility for the display of transverse fissures upon the steel manufacturers The extreme vagueness and intangibility of the comments are obstacles to their investigation Rails are made in shapes in strict conformity to templates Specifications governing their chemical composition are met The amount which a rail shall contract in cooling from the hot saw to atmospheric temperature is often prescribed A limit is at times placed upon their straightness prior to gagging Drop tests are made and a final inspection for surface These are features which rail makers are called upon to meet If a relation is established between the chemical composition and primitive physical state of the rails and their endurance of track conditions such information must come from the users of the rails The opportunity to acquire such information is not at the open hearth furnace nor at the train of rolls of the rail mill

The making of steel as well known is conducted on a colossal scale The handling of great quantities of raw material is an every-day occurrence Necessarily the process is one which practically must be under complete control Current discussions of open-hearth operations among steel makers refer to refinement of details not departures from general practice

From the ore to the finished rail the different stages of fabrication are conducted with system and regularity Ore reduced in blast furnaces to pig iron is conveyed to a mixer, a reservoir of hot metal For weeks or months hot metal is intermitting charged and withdrawn from the mixer in its passage from the blast furnaces to the open-hearth furnaces

At the open-hearth furnaces the interval of time in making a heat of steel may range from 10 to 11 hours This interval of time includes throwing in limestone for slag-making purposes, charging cold steel scrap, charging hot pig iron from the mixer, furnace additions of ore and flourspar, recarburizing metal, and ferromanganese when ready for tapping, ferrosilicon being added to the metal when in the ladle

Quantities handled in making a typical heat would be something like the following Limestone, 28,000 pounds, scrap, 121,000 pounds, cold metal, 14,000 pounds, hot metal, 105,000 pounds, recarburizing metal, 35,000 pounds

The precision with which the chemical composition called for by specifications under which rails are being furnished and the composition attained are given in the example which follows:

	C	Mn	P	S	Si
Composition called for	0.64 to 0.77	0.60 to 1.00	0.040	-	0.15
Composition attained	.64	.72	.031	0.032	.16

The particular heat to which the above figures refer, furnished 50 ingots, 19 by 19 inches each. It would be fantastic in the making of this heat to predict its relation to the ultimate display of transverse fissures in the rails into which it would be rolled, or which particular ingot of the 50 would be prone to display such a type of fracture.

In the rolling of the ingots of one heat into rails the speed of rolls and reductions in the several passes would not be unlike the rolling of other rails of the same weight. If rail-mill conditions exert an influence on the formation of transverse fissures, that influence should extend to all rails. The reduction of an ingot requires the expenditure of mechanical work, the energy required increasing with the speed of reduction. Work is done in overcoming plastic resistance of the hot metal.

In the forming passes the mechanical work would vary in different parts of the cross section of the derivative shapes. The mechanical work done on steel at the higher temperatures has little if any influence on the physical properties when cold. However, as atmospheric temperatures are approached the mechanical work done on the steel has a decided influence on its final properties.

Throughout the passes of the rail mill the head of the rail remains at a higher temperature than other parts of its cross section. If cold rolling, in the mill sense, promotes the formation of transverse fissure, they would be expected in other parts of the rail than where they are prevalent.

Investigations conducted by the bureau of safety have shown no inherent reason for attaching responsibilty for the display of transverse fissures to manufacturing conditions, either in the making of the steel or in the rolling of the rails.

RESULTS OF A QUESTIONNAIRE SUBMITTED TO REPRESENTATIVES OF LEADING RAILROADS AND STEEL MILLS

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RESULTS OF A QUESTIONNAIRE SUBMITTED TO REPRESENTATIVES OF LEADING RAILROADS AND STEEL MILLS

That different points of view have been taken by the railroads and the steel makers has been patent to all. To aid in bringing about a better understanding between steel makers and the users of rails and establish upon what features they were in a state of mutual accord, and by elimination ascertain upon what points differences of opinions attached, a questionnaire was prepared and presented to representatives of leading railroads and steel mills. Replies thereto were tabulated and brought before these representatives at meetings participated in by them together with the bureau of safety.

The questionnaire took up matters of fact, in a general statement of transverse fissures, references were made to manufacturing conditions from the ingot to the last pass of the rail mill, presenting the subject of gaging, acceptance tests, drop tests, the effects of aging on the physical properties of rails, track conditions and their effects on rails, on the relations of manufacturing details to the formation of transverse fissures, concerning an item in the program of the American Railway Engineering Association of 1924 (having reference to permissible wheel loads), carbon steel rails of higher manganese content, interrogatories having reference to a 90-pound rail in which a large number of transverse fissures were displayed, and in conclusion a count in the questionnaire which read: "Have you identified any manufacturing condition (omitting consideration of shattered zones) which you regard responsible for the display of transverse fissures?"

Beneficial effects seemed to result from the presentation of the questionnaire. Definite questions brought out definite replies revealing the fact that upon many features, those which were most essential, no practical differences in points of view really existed. It was concurred in that no foreign inclusions of any kind were at the nuclei of transverse fissures, furthermore that the microstructure of the steel at and in the vicinity of a transverse fissure did not display any peculiarity not found in other parts of the steel. It necessarily followed that there was no manufacturing condition to be identified where neither any foreign inclusion, abnormality in structure, or chemical composition was to be found, hence the replies to that count of the questionnaire were negative.

It is, of course, well known that steels in general are streaked in some degree and that the streaks exert an unfavorable influence on some types of fracture. Slag inclusions, or more properly, silicates, are present in acicular lines which constitute lines of structural weakness. Such lines lead to split heads. When the split head fracture is vertical it does not seem to influence a transverse fissure. When the split head is horizontal it may lead to a compound transverse fissure.

The surfaces of the transverse fissure first shown had lost their silvery luster and were darkened, indicating that it had reached the surface of the head of the rail prior to the time of the accident In other derailments of this kind the transverse fissures had reached a corresponding stage in their development Strictly speaking there was a possibility for the detection of the fissure and the accident being averted, but not a probability of doing so The engine of the derailed train doubtless completed the fracture of this rail, although this transverse fissure had reached the surface of the head before this train entered upon it how much earlier can not be said

The rate of growth of a transverse fissure is a matter of extreme importance to acquire information upon, but obviously can not be told from surface inspection For a period of 16 years—that is, since a transverse fissure was recognized and described as a distinct type of rail fracture—information upon its rate of growth has not been at hand Opportunity or means for acquiring such information appears to have been presented some three or four years ago but unavailed of, reference is now being made to the Sperry transverse fissure detector

The detection of transverse fissures in rails in the track and measure of their relative sizes seems to be accomplished in the device above mentioned This accomplishment comprises one of the most important features connected with the display of transverse fissures It is desirable to ascertain what degree of severity in service conditions lead to the formation of this type of fracture Transverse fissures prevail in some localities, they are unknown in others In locations where they prevail the relation of definite service conditions to their display has been shown

On some roads their distribution is quite general On others they are segregated within narrow limits, apparently influenced by local conditions

In respect to their avoidance or overcoming the formation of transverse fissures the outlook is not promising In fact, no encouragement whatsoever is presented Intense study has not yet detected any specific cause for their prevalence in one heat of rails over another of similar composition, nor why from a metallurgical point of view one rail should display a transverse fissure after a very brief interval of time in the track and another endure for a long period It is logical to assume that phenomena of this kind depend upon something else than a consideration of the initial physical properties of the rails themselves The factors to be given consideration are the strains and stresses to which the rails are exposed If proof attaches the causes of fracture to conditions of service, no other consideration is necessary to explain the reason for the prevalence of fractured rails

REPEATED ALTERNATE STRESSES

In regulating the loads which are put upon metals the results of laboratory tests on repeated alternate stresses furnish useful information The basic feature in all engineering practice refers to the matter of ultimate endurance of the materials employed It is believed there is a limit in the ability of steels to endure stresses, a stress of a certain magnitude below which the metal possesses unlimited endurance In repeated alternate stress tests the line of demarkation between limited and unlimited endurance of stresses in steels is seemingly well defined

Illustrating this feature, using the results of tests on a steel of 0 82 carbon content, the tensile test of which gave an elastic limit of 64,000 pounds per square inch, tensile strength, 142,800 pounds per square inch, elongation 7 per cent, contraction of area 11 8 per cent, the relative ability to endure stresses of different magnitudes were as follows

Under repeated alternate stresses of 60,000 pounds per square inch, let an ordinate of 1 inch graphically represent the endurance of the metal At 45,000 pounds per square inch the ordinate representing its endurance would then be 16 inches in height With a further reduction of stress of 5,000 pounds per square inch, the ordinate at 40,000 pounds per square inch would have a height of 452 feet, and the latter without reaching final rupture of the metal

Corresponding results would no doubt be displayed by steel in whatever positions it may be used Steel rails have their defining stresses below which they would display unlimited endurance, but such loads on wheels would be so low as to preclude their consideration It should be definitely impressed on the minds of all that track conditions impose overstraining forces The rail problem is to find the steel which will endure overstraining forces of longest duration without rupture Answers to this question must come from the track

CONCLUDING REMARKS

In this report circumstances have been described relating to the accident which is its main subject The accident was caused by a transverse fissure in one of the rails of the track In the reports of this bureau other accidents have been described which resulted from transverse fissures On the present occasion there was no essential difference in respect to the fracture of this rail over others which have taken place The present accident was characterized by reason of the large loss of life and personal injuries which it caused are most difficult to explain. The difficulties are enhanced by the absence of exact knowledge of what stresses are under consideration.

Reliable track records yield the most promising data in the final summation of the endurance of rails. Recognition of what constitutes the most desirable chemical composition in rail steel must come from track records. In perishable material greatest value will attach to those means or the device which will give the earliest warning of impending danger.

At present there is no remedy known for the prevention of transverse fissures, current track conditions being considered. It seems, however, that the matter of their detection has been solved, constituting the greatest accomplishment yet heralded.

SUGGESTIONS

A report of this kind would hardly be complete without appending some suggestions or recommendations intended to improve present conditions. A few features will be enumerated which have a direct relation to the serviceability of rails, while reference will also be made to some physical phenomena which might properly be made the objects of advance study.

Remarks will be introduced under three general headings:

1. Steel making and the fabrication of steel rails.
2. Railroads or the users of steel rails.
3. Research problems.

1. Steel rails would be improved against the display of certain common types of fracture by the elimination of both internal and external seaminess. Internal streaks or seaminess in the head and external seaminess at the lower surface of the base are two critical parts in the cross section of a rail. Improvements at these two places would prolong the lives of certain rails.

Generically split heads and base fractures belong to the same type of rupture. Each results from the influence of a lateral force and each has its origin at a longitudinal seam or streak.

Impinging wheel pressures set up simultaneous strains in two directions in the top of the head. One component tends to form transverse fissures, the other to form split heads.

When lateral flow of the metal of the head encounters a slag or silicate streak opportunity is presented for the formation of a split head.

In the metal of the base crosswise service stresses in the flanges lead to longitudinal fractures which originate at seams or laps.

After the same fashion that longitudinal cracks in the base are diverted and form crescent-shaped fragments, horizontal split heads

It may be said that practically all of the ordinary conditions of service expose rails to destructive influences This member in the track structure is habitually called upon to resist destructive forces If all parts of the cross section of a rail were exposed to the maximum strains which some parts are, there could be no such a thing as track structures as we now have them The possibility of maintaining a track relies upon the reinforcement of the overstrained portions of the rails by the understrained parts

Two principal features are presented in the track-structure problem, one is to find the steel which has the greatest endurance to track stresses, the other is the detection of incipient fractures, whether they are transverse fissures or other types of fracture The review of the physical properties of steels introduced in the present report together with the description of those inherent to all steels enumerates features which are of common observation Practically all the vicissitudes to which steels are exposed are encountered in some degree by rails in service For the most part they are features which manufacturing conditions do not deal with

Specifications governing the acceptance of rails perforce can not prescribe against the effects of destructive forces They can only call for certain primitive properties in the finished rails If service stresses are confined well within the primitive physical properties prolonged endurance will be realized Since service stresses of rails do commonly transcend those critical limits prolonged endurance can not be expected

In answer to the question what causes transverse fissures, the reply is a brief one They are caused by the introduction of internal strains in the head of the rail set up by the action of the wheel pressure on the running surface of the head The internal strains directly introduced are strains of compression To resist these strains of compression the metal next below is put into a state of tension Transverse fissures are formed in that zone of metal which is put into a state of tension These words virtually repeat the explanation which was given in the report of the commission on the Manchester accident on the Lehigh Valley Railroad of August 25, 1911

To the query, why do some rails display transverse fissures while others do not, or have not, the general reply is equally brief Rails differ in their ability to endure stresses If the reason is not shown in their physical properties or structural state, it is presumptive evidence they have been exposed to different orders of treatment The physical properties of steel are not inconstant or capricious, but questions of durability under varying stresses are among those which

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are diverted from their courses and form compound transverse fissures. Vertical split-head fractures lead to the separation of the head from the web.

These two causes of rail fractures, internal and external seaminess furnish problems for the steel mills to overcome or minimize.

Shrinkage cracks, in the heads and bases of rails, when and under what conditions they reach a maximum and rupture ensues, essentially constitute a research problem.

2. The railroads occupy a favorable position to acquire data upon the longevity of rails in respect to the display of transverse fissures. Material is at hand for comparing the properties of rails which have displayed transverse fissures at widely differing ages. The problem is to ascertain whether any physical, structural, or chemical factor is responsible for the variable behavior of rails in the track or whether differences in longevity are due to undefined track stresses.

3. Research problems specifically referring to steel rails, or in fact to steels in general, are somewhat numerous. Basically, steel can be used for rails, because it is capable of acquiring and retaining internal strains. They are necessarily both of tension and compression. Of what does this common property consist? Can the presence of a strain, positive or negative, be recognized in any other manner than by permitting its release?

Exhaustion of toughness may be reached with or without distortion of the grains. By what means can exhaustion of the ability to permanently elongate be recognized without subjecting the steel to its limit of ultimate resistance?

When changes in density occur, what are the interrelations of the microconstituents? These and kindred queries present themselves in studying the mutual relations, causes and effects, of wheels and rails. Information upon these basic features would be a contribution to the physics of steels in whatever situation this important metal is used.

Respectfully submitted.

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