INTERSTATE COMMERCE COMMISSION

REPORT OF THE CHIEF OF THE BUREAU OF SAFETY COVERING INVESTIGATION OF AN ACCIDENT WHICH OCCURRED ON THE BALTIMORE & OHIO RAILROAD AT GLENWOOD, W VA, ON DECEMBER 11, 1919

JANUARY 14 1921

To the Commission

On December 11, 1919, there was a derailment of a passenger train on the Baltimore & Ohio Railroad at Glenwood, W Va, which resulted in the injury of nine passengers and one express messenger As a result of the investigation of this accident I respectfully submit the following report

This accident occurred on that part of the Ohio River Division extending between Kenova W Va, and Parkersburg, W Va a distance of 129 2 miles, and is a single-track line over which trains are operated by time-table, train orders, and a manual block-signal system The accident occurred a few feet west of the station at Glenwood Approaching this point from the west there is a tangent 860 feet in length followed by a 3° curve to the left 923 feet in length, the derailment occurred on this curve about 210 feet from its eastern end The grade in the vicinity of the point of the accident is level The track is laid with 75-pound rails, 33 feet in length, with an average of 18 white oak and treated ties to the rail, single spiked and ballasted with about 9 inches of sand and cinders, no tie-plates are used Under time-table rule 5 the speed limit of passenger trains is 45 miles an hour The weather at the time of the accident was clear

The train involved in this accident was eastbound passenger train No 78, en route from Kenova, W Va, to Pittsburgh, Pa It consisted of 1 combination mail and baggage car, 1 express car 2 coaches 2 sleeping cars, 1 coach, and 2 baggage cars, in the order named, hauled by engines 1410 and 1408, and was in charge of Conductor Roush and Enginemen O'Connor and Hall It left Kenova at 10 20 p m on time, left Huntington, the last open telegraph office, at 11 12 p m 12 minutes late, and at about 11 50 p m was derailed at Glenwood, 22 1 miles east of Huntington, while traveling at a speed shown by a speed recorder to have been between 42 and 43 miles an hour

Engine 1410 was not derailed, while engine 1408 was entirely derailed with the exception of the leading pair of engine truck wheels, this engine came to rest in an upright position 710 feet east of the point of derailment with the wheels close to the rails The combination mail and baggage car became separated from the tender of engine 1408 coming to rest about 150 feet behind the engine with its forward truck resting on a passing track, located on the right side of the main track east of the station, and the rear truck across the main track The express car was separated from the combination car by about 25 feet and was derailed on the left side of the main track, inclined toward the left at an angle of about 45°, the two coaches and the two sleeping cars were also derailed to the left but remained more or less upright The three cars on the rear of the train remained on the track Figure No 1 is a view taken from the west end of the station platform looking east, Figure No 2 is a view taken from about the same point showing the sleeping cars Brainard and Hewlett the last cars in the train to be derailed

The engine crew of engine 1410 did not notice anything unusual in approaching Glenwood their first knowledge of anything wrong being when they felt the air brakes applied in emergency Engineman Hall, in charge of the second engine 1408, felt his engine lunge and tried to apply the air brakes, but the motion of the derailed engine kept him from reaching the cut-out cock until the engine had nearly stopped He thought the driving wheels of his engine were the first to derail The train crew did not know that there was anything wrong until they felt the cars in which they were riding leave the rails

After the accident Enginemen O'Connor and Hall and Conductor Roush examined the track and found that there was a broken rail on the left side of the track at a point about 2 feet behind the rear of the second sleeping car On his previous trip westbound Engineman Hall had felt nothing unusual when passing this point Conductor Roush did not see any wheel marks on the ties west of the point where the rail was broken, which statement was verified by Flagman Price Assistant Division Engineer Bailey, who was a passenger on the train, found the end of the broken rail resting on a tie, about 3 inches from the side of the tie, the break appeared to be new, but showed signs of having been rubbed slightly

Track Supervisor Landers had been over this part of the road on the morning of the accident, but had noticed nothing unusual He said there were no flange marks west of where the rail had broken, that the fractured surface indicated a new break Supervisor Landers had made a general rail inspection on November 24, and had found that some of the ties needed renewing. In the vicinity of the point of accident, however, the ties were all good with the exception of the one which was under the first break in the rail.

Section Foreman Oldaker had worked on the track in the vicinity of the point of accident about a week previously, and had been over it the preceding day, at which time he did not discover anything wrong. He said he had recently renewed the ties under the rail which first broke, and that they were in good condition.

Trainmaster Moran, who reached the scene of accident at 7 a. m. December 12, said that the receiving end of the rail remained in the track, fully bolted. The tie on which the broken end rested was broken on the end, while there were splits in it which appeared to have been there for some time, as well as some other splits which were new; he found the ties on either side of this tie to be in good condition.

The rail which broke was rolled in 1910 and laid in the track at the point of accident in the same year. The receiving end was intact for a distance of 3 feet 6¾ inches, while the leaving end was intact for a distance of 4 feet ⅝ inches. The intervening section of the rail was broken into many pieces, 10 of which were recovered. While the evidence is conflicting as to whether the broken end of the receiving portion of the rail rested on a tie, examination of the bottom of the base of the rail showed that the worn spot made by the tie was about 2 inches from the break.

Measurements of the track covering a distance of about 700 feet immediately west of the point of derailment showed it to have been maintained in good condition, while careful examination of the engines and other derailed equipment failed to disclose anything which could have caused the accident.

Acknowledgment is made of the cooperation in this investigation of the Baltimore & Ohio Railroad, Mr. J. R. Onderdonk, engineer of tests; the Carnegie Steel Co., Dr. J. S. Unger, manager central research bureau; the New York, New Haven & Hartford Railroad, Mr. H. P. Hass, engineer of tests; the Bridgeport Brass Co., Mr. W. R. Webster, vice president; and the Bethlehem Steel Co., Mr. H. R. Christ, metallographist.

This accident was caused by a broken rail. The investigation to determine the reason for the failure of this rail was conducted by Mr. James E. Howard, engineer-physicist, whose report follows:

REPORT OF THE ENGINEER-PHYSICIST

The rail which broke and caused the derailment of train No 78 was rolled by the Carnegie Steel Co , in the month of April, 1910 Its weight was 75 pounds per yard, A S C E section, Bessemer steel, heat No 1093, and branded "Carnegie 1910 E T IIII 75 A" It was the low rail of a 3° curve The ladle analysis of the steel was as follows C 46, Mn 90, P 0 093, S 0 046 Check analysis of the rail confirmed the ladle analysis

Figure No 3 is a diagram showing fragments into which the rail was broken, some parts of the rail not having been recovered after the accident The recovered fragments showed the several fractures had their origins at the upper surface of the head

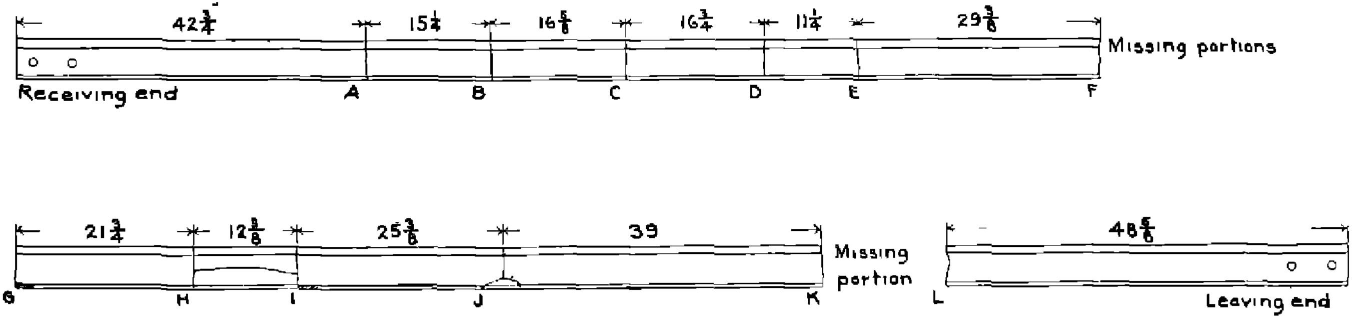
Five of the fractured surfaces exhibited dark colored areas, extending downward from the running surface of the head and located near the gauge side Darkened areas were present at lines of rupture designated by the letters B, C, I, J, and K Fracture C was incomplete at the time of derailment An incipient fracture, at this place was completed after the rail had been removed from the track Figure No 4 show end views of three fractured surfaces on each of which dark areas were present

These dark areas represent progressive cracks, the inception and extension of which led to the final failure of the rail and the derailment of the train

The dark areas marked the location of the most advanced cracks of a series which were displayed at frequent intervals along the running surface of the head The majority were shallow in depth, extending into the rail head only a few hundredths of an inch The more advanced ones penetrated to a depth of three-sixteenths inch, with a maximum length at the running surface of 1 inch The zone, embracing these cracks, was on the top of the head near the gauge side Cracks in the most advanced stage reached the edge of the head

Figures Nos 5a and 5b illustrate the appearance of these cracks before and after the rail had been pickled in hot acid They assumed a pronounced aspect due to the pickling, which also revealed a slightly shattered condition of the running surface along the middle of the top of the head The presence of these short crosswise cracks was characteristic of other rails in the vicinity of the place of derailment

The cracks were shown to be of thermal origin There was evidence on the upper surface of the head of exposure to a high temperature attended with thermal hardening of the metal The hardened metal was of shallow depth, below which the normal structure of the steel prevailed



Low rail of 3 degree curve Branded "Carnegie 1910 E T IIII 75 A" Heat number 1093

FIG 3 — Diagram of broken rail Incipient cracks at fractures B C, I J, and K, top of head, near gauge side

Respecting the hardness acquired by the heads of rails in service it is of two kinds, mechanical hardness and thermal hardness The running surfaces of all rails are exposed to mechanical hardening, due to the cold rolling action of the wheels Thermal hardness results from sudden heating, raising a portion of the rail to a high temperature, followed by sudden quenching No difficulty is experienced in the identification of the two kinds of hardness under the microscope and even a file may be used for the purpose

The mechanical hardening of rails under current wheel loads is universal Flattening of the granular structure of the steel occurs in such zones This type of hardness exhausts the ductility of the steel, embrittling and weakening the rail as a whole, although not attended necessarily with the formation of incipient cracks At this stage the shape of the grain of the steel may be restored by the process of annealing and with it the strength and ductility of the rail Loss in ductility under the cold rolling action of wheel loads represents an intermediate stage in the service of rails, and it may be the precursor of rupture

The maximum degree or state of mechanical hardness is acquired after the passage of a considerable number of wheels over the rail, different elements along the running surface being subjected in succession to the kneading action of wheels of different contours of treads

Thermal hardness in the head of the rail results from the slipping of wheels, wheel-burning, so called This also is a matter of common occurrence in certain situations, and which investigation shows to be more generally prevalent than the appearance of rails in the track suggests Thermal hardness may result from the slipping of a single pair of wheels or as in the case of mechanical hardening it may result from the action of a number of wheels Heat effaces thermal hardness, and surface annealing may occur over hardened zones by subsequent moderate heating of the head of the rail The source of heat in these cases comes from the frictional resistance between the wheel and the rail

There are points of difference to be considered between mechanical hardness and thermal hardness In the case of mechanical hardness loss in ductility may be partial or complete with respect to the ability of the rail to display ductility under bending stresses, and while ductility may have been destroyed as against bending stresses, residual ductility may still remain, the steel retaining its ability to display further distortion under the kneading action of wheel pressures

Steel thermally hard is incapable of displaying appreciable ductility under any condition It is brittle whether under tensile stress or whether under high wheel pressures This inability of thermally hard steel to display ductility is sufficient to account for the cracks witnessed on the running surface of the present rail The results of microscopic examination clearly established the fact that the crosswise cracks in the head of the rail were in steel which had been thermally hardened

The structural state of the rails is shown by photomicrographs, figures Nos 6 and 7 Figures Nos 6a and 6b represent the metal next the running surface of the head, on longitudinal and cross sections respectively Figure No 6a shows a shallow zone of the hardened metal next the running surface of the head below which the normal structure of the steel appears Figure No 6b shows the hardened surface metal near the gauge side of the head below which flattening of the grain had occurred The flow was toward the gauge side The magnification of these photomicrographs is 100 diameters

Figure No 7a shows an incipient crack in the hardened zone which had not penetrated to the normal metal Figure No 7b illustrates the junction of the hardened surface metal with the normal structure of the interior of the head The magnification of these photomicrographs is 300 diameters These cuts show the part which heat played in the thermal hardness at the running surface of the rail

The evidence presented by this rail raises two leading questions, one pertaining to the conditions which caused the hardening of the metal, the other having to do with the manner of development of the series of surface cracks Thermal hardening of rails in service results from the slipping of wheels, and from that cause only Driving wheels may slip in the starting of trains and all wheels may slip when brakes are applied in stopping a train or in retarding its speed Further, the difference in length between the outer and inner rails of a curve requires the wheels on either the high or the low rail to slip The individual action or the combined action of these two features—slipping by accelerating or retarding forces, and slipping by reason of the difference in length of the high and low rails of a curve—must account for the heating of this rail The effect of curvature of the track would seem a negligible factor, and ordinarily be omitted from consideration, as well as differences in the tape size of mated wheels, nevertheless minute cracks visible on other rails in the vicinity of the place of derailment were on curved track and very sparingly shown on tangents

In respect to the manner of development of these surface cracks, the tractive force of the driving wheels of the engine tend to force a film of surface metal in a backward direction The resistance of the car wheels is in the opposite direction and forces the metal forward Under braking conditions the drift of all wheels is forward These movements alternate on a single-track road

Concerning the supporting power of a thin film of hardened metal and its ability to transmit and distribute the intense impinging pressures of the wheels, herein seems an opportunity to develop such a series of short crosswise cracks as the rail exhibited The chemical composition of the steel shows this rail to be one of medium hardness, which normally should respond to the cold-rolling effects of the wheels with surface flow of the metal The impinging pressures tending to cause a caving in of the hardened surface metal together with the alternate tractive forces of driving wheels and effects of the train wheels represent the conditions under which this rail worked, and as such they constitute the forces which were responsible for the development of the series of surface cracks

The appearance of the rails in the track affected with these minute crosswise cracks did not suggest the presence of hardened metal The slightly shattered surface shown when the head of this rail was pickled together with the hardened metal revealed by the microscope constituted the first evidence acquired upon the hardened state of the surface metal

The failure of this rail illustrates a type of common occurrence, but an unusual example of its kind Its manner of development makes it one of deep concern The majority of the cracks in the head were of limited depth and at their present stage of development were not menacing to the strength of the rail Their ultimate extension however, was highly probable, while certain of them had extended, weakened the rail, and precipitated this derailment As a modified example of wheel burnt rails this must be regarded as a serious one

There are thousands of wheel-burnt rails in current service in track and it is difficult to judge whether their presence is negligible or serious They all modify or impair the properties of the rails in some degree No positive means are at hand in the majority of cases for ascertaining the extent of their influence Within a restricted area or volume of metal they present the results of exposure covering a wide range of conditions The industrial arts afford no parallel examples of such sudden heating as that done by the slipping of wheels on rails

The seriousness of the incipient cracks in the head of the rail was made manifest by bending and drop tests made on the recovered fragments, as the following tabular exhibits show

BENDING TESTS

Ends supported on bearings 22 inches apart, loaded at the middle

How tested	Ultimate strength, total pounds	Manner of failure
Base in tension	191,800	Broke through bolt holes in web
Head in tension	71,600	Broke at incipient crack in head, 0 75 by 0 22 inch
Sidewise test, gauge side of head in tension	42,000	Broke at incipient crack in head, 0 75 by 0 18 inch

DROP TESTS

2,000 pounds tup, 3 feet between supports

Base in tension		Rail stood two blows from height of 15 feet without rupture, nicked and broke on the third 15 foot drop
Head in tension		Rail broke on first blow of tup from height of 1 foot

Supplementary data will be presented, the results of strain gauge measurements on wheel-burnt rails which were collected for this examination by the engineer of tests of the New York, New Haven & Hartford Railroad The rail sections were examined in the condition they came from the track, and again after special treatment intended to illustrate certain phases through which wheel-burnt rails pass The conditions which in wheel-burnt rails are crowded into a limited area were reproduced in detail on a scale sufficient to permit of measurement, and the establishing of numerical values

The examination of these supplementary rails was made in the laboratory and shops of the New York, New Haven & Hartford Railroad at New Haven Conn , on which occasion a considerable number of rails were examined for the presence of shattered zones in the central parts of their heads In all, 37 rails were examined In respect to shattered zones, none of the series was found affected in that manner

The rails on which additional observations were made respecting the effects of wheel burning were as follows

Mark	Maker of steel	Weight of rail	Year rolled	Heat No
		Pounds		
A	Bethlehem Steel Co	107	1918	22423-7A
B	do	107	1918	22423-7A
C	Maryland Steel Co	107	1917	2X4225B
D	do	107	1917	2X4225B
E	do	107	1917	2X4222B
6	Pennsylvania Steel Co	100	1908	25046C
15	do	100	1911	24129B
29	do	100	1911	25073D

Several other rails were pickled and photographed and cuts showing their appearance are herein inserted.

Rails designated by the letters A to E were examples of wheel burning, those designated by numerals were taken from the series of rails examined for shattered zones. None of the rails exhibited a severe instance of wheel burning in respect to the extent of the affected surface. The use made of the sections was chiefly in subjecting them to special treatment illustrative in detail of phases which wheel-burnt rails experience.

In the examination of these sections it was found that rail heads are frequently affected over a greater length than their appearance in the track indicates. Pickling brought into view affected zones the presence of which would hardly be known, certainly not under casual observation.

Figures Nos. 8a and 8b illustrate the appearance of the head of wheel-burnt rail B before and after pickling. Figures Nos. 9, 10, and 11 represent rails Nos. 6, 18, and 29, as they appeared after pickling. Evidence of wheel burning on these three rails before pickling was very slight. Figure No. 12 shows the head of rail No. 14 upon which pickling furnished no evidence of wheel burning. Several longitudinal seams, however, were brought into view on the running surface.

Rail B, figure No. 8a, had a well-defined wheel-burnt spot on the gauge side of the head. Pickling revealed affected metal along the head beyond each end of that spot. A wheel-burnt streak was disclosed on the head of rail No. 6, illustrated by figure No. 9, located just outside the center line. Figure No. 10 represents a rail with a mashed head. An affected streak was found along each edge. A flange-worn rail is illustrated by figure No. 11. There was no evidence of wheel burning on the gauge side. A streak of affected metal was displayed near the outer edge of the head.

Continuous streaks are due at times to the slipping of wheels of the train under braking conditions. Long streaks also may be made by driving wheels of the engine. Blue-black streaks several inches in length occur when driving wheels slip as trains are gaining headway.

On some rails slightly wheel-burnt, the effects are obscured or effaced by the passage of other wheels. Slight abrasion of the running surface may be rolled smooth by subsequent wheels. Hardened metal may be partially annealed, the immediate surface restored to a softened state and then rolled smooth. Under such circumstances the running surface presents no evidence of the vicissitudes through which the rail has passed.

Concerning the lines of demarkation between running surfaces which have been simply cold rolled, those which have been exposed to loss of metal by abrasion as commonly experienced by rails, those of greatly roughened surfaces and those which have been wheel-burnt in different degrees, one effect merges into another, rendering the lines of demarkations obscure

Microscopic examination of wheel-burnt zones was made on the material of these supplementary rail sections, figures Nos 13a and 13b, 14a and 14b, and 15a and 15b, showing some of the results Figure No 13a represents a cross section of the head of one of the rails, showing the hardened zone at the running surface Incipient cracks appear in the hardened metal Below the hardened zone the grain of the steel is flattened with trend toward the gauge side The magnification of the cut is 60 diameters

Figure No 13b is also a cross section at 60 diameters magnification A greater depth of hardened metal prevailed at this place An incipient crack is here shown which in its development separated into two branches This type of crack in this place possesses more than ordinary interest and aids in explaining the manner of development of the cracks found in the hardened zones

The bifurcation of this crack is similar to that of fractures made in bending tests, one of which is shown on the diagram of the broken rail, figure No 3, and designated by the letter J It is a type of fracture which might result from the flow of unhardened metal below the hardened zone allowing the intense local impinging pressures to crack the surface metal

The supporting power and distributive ability of a zone of hardened steel depends upon its depth Wheel-burnt rails with different depths of hardened metal different axle loads on wheels of different diameters and contours of treads, constitute variable factors which influence the manner of failure of rails The shallow depths of hardened metal in the present cases would afford opportunity for the development of surface cracks by yielding of the interior normal steel, the hardened surfaces being incapable of responding to wheel pressures by flow of metal

Figures Nos 14a and 14b are photomicrographs, the former showing flaking off of the hardened layer of surface metal, the latter the development of a crack in the hardened zone which it fully separated Flaking off of the hardened metal is of advantage, favorable toward preserving the integrity of the balance of the rail by arresting the downward progress of the crack The crack represented in the latter figure is oriented the same as those witnessed in the rail which caused the present derailment With the extension of such a crack into the normal metal, the complete rupture of the rail would not appear a remote contingency

Figures Nos 15a and 15b each show a layer of annealed metal above a hardened zone The polishing and etching was regulated in a manner suitable to show this contrast between the annealed and the hardened steel In figure No 15a the black band represents annealed metal resting upon hardened metal The steel of normal structure, not shown here was located below the hardened zone Figure No 15b represents the same condition at another wheel-burnt section The annealed metal above the hardened steel showed flattening of the grains

Annealed surface metal represents a subsequent wheel effect the result of moderate heating of the immediate surface of the rail head on a zone previously wheel burnt and hardened This condition of the surface metal favors the obscuration of moderate wheel burning in presenting softened metal for the wheels to act upon The physical characteristics of the steel are thus changed by conditions experienced in the track, effecting radical changes in strength and structure, changes which are destructive in their character

A series of diagrams are presented showing the primitive internal strains in the rails due to cold rolling by the wheels and those which represent the results of wheel burning In order to have measurable quantities to deal with representing the influences in detail which are closely grouped in wheel-burnt zones, specially prepared sections were made use of Reference lengths were established on these sections as usual when preparing for strain gauge measurements The internal strains in the sections as they came from the track were first measured followed by special treatment of channeled sections from the rail heads and strips from the flanges The special treatment consisted of the operations of heating, quenching and annealing

Diagram No 1, has entered upon it the results obtained with rails A and C Reference lengths were located on seven elements as indicated on the first figure of each rail one gauged length on each side of the head three on the running surface, and one each at the fillets connecting the head and the web The total changes on these several gauged lengths are entered on the cross sections which are shown in succession on the diagram the shaded areas representing the condition of the rail or its head at the time the observations were made The strains released as the cross section of the head was changed by planing away portions of the metal, represent the joint effect of the cold rolling of the wheels and the influence of the wheel burning The part which each influence played can not be stated The strains of compression along the top of the heads were not above the average, somewhat less than usual, whence it may be inferred that the effect of wheel burning, of the limited degree experienced by these sections, did not increase the internal strains which result from the cold rolling action of the wheels, and may have diminished their influence in some degree

Internal strains in a rail in a free state with respect to external loads, are in equilibrium Whenever a change is made in the cross section such as planing away a portion of the rail, a rearrangement of the internal strains occurs When the cross section is reduced to elementary strips the total changes in length represent the strains under which those parts existed when the rail was intact The relation between strains and stresses, expressed by the modulus of elasticity of the steel is known hence the values of the strains may be converted into stresses or pounds per square inch Examined in this way, knowledge is obtained of the effects of wheel pressures, cooling strains, and those which result from heating and quenching

Each change in the cross section of a rail made by planing away a portion of the metal as previously stated, is attended with a change in dimensions of the remaining part Likewise each special treatment given the rail or a portion of it is attended with a change in dimensions Changes may occur in plus or in minus directions—that is, the rail may be so treated that portions will be made longer or they may be made shorter These strains converted into their corresponding stresses amount to many thousand pounds per square inch Not uncommonly they are equivalent to stresses far in excess of those which are regarded as permissible loads on permanent structures of iron and steel

The head of rail A was detached from the web and base by a machine tool cut in a shaper leaving the head 2 inches deep When thus released from the influence of the web and base the head assumed a slightly convex shape crowning on the top The gauged lengths on the running surface increased in length those at the fillets of the web decreased The maximum changes in lengths were plus 0 0015 inch and minus 0 0021 inch, the corresponding stresses of which are 4 500 pounds per square inch compression and 6,300 pounds per square inch tension The changes at this stage represent only a partial release of the internal strains in the head of the rail Further changes occurred as the dimensions of the detached head were reduced When the head was planed off from the underside to a depth of $1\frac{3}{8}$ inches, one gauged length showed a total increase of 0 0024 inch, equivalent to 7 200 pounds per square inch compression The head was next channeled leaving walls one-fourth inch thick whereupon a total extension of 0 0040 inch was observed, equivalent to 12,000 pounds per square inch compression Different elements on the channeled section showed different changes in length The internal strains were variable in different parts of the rail

The channeled section was box annealed, in lime, at a temperature of 1,400° F This resulted in a shortening of the section on each of the gauged lengths The greatest decrease in length was 0 0024 inch, which is equivalent to 7 200 pounds per square inch In an earlier report the results of successive annealing of a piece of rail in full cross section were given which in the aggregate amounted to a shortening of nearly 1 2 inches referred to a 33-foot rail Annealing performs two functions—it relieves internal strains and increases the density of steel which has been cold rolled or thermally hardened A complex state of strain is set up when a portion of the cross section of the rail is exposed to annealing temperatures The dilatation of the steel during rise of temperature here becomes a factor The expansion of steel due to rise in temperature of only 300° F is practically that of its extension under a stress of 60,000 pounds per square inch

Another feature to consider is the lowering of the elastic limit of the steel as the higher temperatures are reached With a lowering of the elastic limit locally the influence of the colder portions predominates and modifies the resulting internal strains It is sufficient to enumerate these variable factors to illustrate the complicated nature of the problem involved in the matter of wheel-burnt rails

Rail C was examined in the same manner as rail A The internal strains liberated in the channeled section reached a maximum of 0 0058 inch, which is equivalent to a stress of 17 400 pounds per square inch compression The maximum contraction during annealing was 0 0026 inch, equivalent to 7,800 pounds per square inch stress

Diagram No 2 has entered upon it the changes which occurred on a section of rail B The head was detached from the web and base and afterwards channeled as described in the preceding rails The results were similar in kind as before noted The channeled section was heated in an electric furnace to a high scaling temperature The approximate effect upon the gauged lengths are shown on the diagram Each gauged length was shortened The holes defining the reference lengths were in bad order, due to the scaling The greatest observed change was from plus 0 0030 inch to minus 0 0164 inch, a range of 0 0194 inch In a cold state, a strain of 0 0194 inch is equivalent to a stress of 58,200 pounds per square inch

The middle of the length of the channeled section about 2½ inches, along its upper surface was heated with an acetylene torch to a low yellow color This resulted in a further shortening of the upper part of the channel, attended with an increase in length of the legs The total changes in lengths are shown on next the last figure of the diagram The successive changes due to heating with the torch are entered on the last figure, the seventh of the diagram the differences between the results entered on the fifth and sixth figures This disturbance in length of the section due to heating with the torch will be noted The local heating with the torch introduced a new feature, that of overstrain of the heated portion, the dilatation of the upper surface being opposed by the reaction of the cooler legs of the channel This introduced conditions similar to those experienced by the rail when wheel burning occurs, representing the early stages of local heating and overstrain when the wheels first slip

The results upon rail D appear on diagram No 3 The first stages of the examination were conducted in the same manner as described in rails A B, and C The channeled section of this rail showed a maximum expansion of 0 0044 inch, equivalent to 13,200 pounds per square inch compression It was box annealed, in lime, at a temperature of 1,400° F, which shortened the section of each gauged length in amounts ranging from 0 0010 to 0 0035 inch The maximum strain is equivalent to 10 500 pounds per square inch, if caused by an external force

The channeled section was next heated to a temperature of 1,400° F and quenched in tepid brine This caused a pronounced expansion on each gauged length The maximum expansion due to this operation was 0 0252 inch, equivalent to 75,600 pounds per square inch, the force which would be required to restore it elastically when cold, to its previous length A rest of 44 hours next occurred during which period the hardened section recovered a few ten-thousandths of an inch in length Immediately after hardening, steel is not strictly in a stable condition While in a state of repose, in respect to applied loads or any material change in temperature, hardened steel shrinks in length, the greater part of the shrinkage occurring within a few hours after quenching

The channeled section was next exposed to successively increased temperatures, each of which resulted in a shortening of the section It was heated in succession to 212°, 350°, 500°, and about 1,100° F The temperatures at the second and fourth heating were approximate There was reason for believing that the second heating was somewhat higher than recorded Each higher temperature effected a contraction on each gauged length It was not undertaken to define the rate of contraction, which probably occurred at an accelerating rate as the higher temperatures were reached After final exposure to a temperature of 1,100° F the average length of the section was less than it originally measured in the intact rail

The final heating was done over an open fire It is difficult to raise the temperature of the section uniformly over an open fire, and local overstraining may occur by unequal heating Skilled smiths take advantage of this feature and within limits change the dimensions of members at will by local heating and cooling

The results on rail E are shown on diagram No 4, the treatment of which duplicated that of rail D Its behavior corresponded to and confirmed that of the preceding one, the numerical values being similar in kind Strains displayed in the channeled section were diminished upon annealing, increased upon heating and quenching, slightly diminished during an early period of rest, and showed decided diminution when raised to higher temperatures This rail section was exposed to an intermediate temperature of 800° F, not noted on the diagram, which effected a reduction in length as the other temperatures had done

Diagram No 5 illustrates the behavior of rails Nos 29 and 6, each of which was locally heated with an acetylene torch Rail No 29 was heated along the top of the head a distance of about 7 inches, concentric with the gauged lengths Measured as usual after the rail had returned to normal temperature, each gauged length was found to be of diminished length, in amounts ranging from 0 0010 to 0 0038 inch During the period of applying the torch the heated section of course expanded The metal was softened at the high temperatures locally reached and was reacted upon by the cooler parts of the cross section The final result was a shortening of the head of the rail on each gauged length The internal strains incident to cooling during fabrication and the cold rolling strains from the wheel pressures were modified a new state of equilibrium being established in which the head of the rail was permanently shortened

Proceeding with the cutting up of the rail head, unusually high strains in minus direction were displayed along the sides and at the fillets under the head The channeled section was heated in succession to 212°, 350°, and 500° F without sensible change in length Finally it was raised to a temperature of about 1 100° F The decided shortening witnessed in the channels which had been hardened by sudden quenching was not experienced in this section On two gauged lengths there was an increase in length At the corner on the gauged side of the head, the gauged length increased from plus 0 0028 inch to plus 0 0082 inch, a gain of 0 0054 inch

These results clearly show that local heating effects a change in dimensions of the rail and from this it will be inferred that a similar effect takes place in wheel-burnt rails but there confined to a restricted area The significance of these changes may not be fully known, but when through any combination of causes local strains reach a sufficiently high degree an incipient crack will be developed and ultimate rupture liable to follow The vital feature in respect to maintaining the integrity of the steel is that no two adjacent particles shall be strained to such a degree that continuity is broken

Rail No 6 was heated with an acetylene torch A more localized area was heated than that of the preceding rail The torch was directed to the upper corner of the head on the gauge side The two nearest gauged lengths showed contractions of 0 0047 inch and 0 0050 inch, respectively The more remote parts of the head were less affected Again applying the torch and heating the railhead to a higher temperature than before, the result was a further shortening on these gauged lengths now amounting to 0 0063 inch and 0 0065 inch, respectively The torch was still again applied and directed to the under surface of the head on the gauge side The shortening on the side of the head now reached 0 0178 inch, at the fillet 0 0132 inch The measurements show the relation between the heated and unheated zones, leaving no doubt that local exposure to high temperature and final contraction in length stand to each other as cause and effect It will be borne in mind that the gauged length embracing the heated zone is finally shortened and not lengthened by this treatment

The results upon rail No 15 are shown on diagram No 6 This section of rail was first heated along the middle of the web with a torch Each gauged length on the head was shortened, those on the gauge side of the head and under the head at the fillets slightly predominating The top of the head was next heated, which changed the relations of the gauged lengths effecting a decided decrease in those on the top of the rail

It was undertaken to reverse the direction of movement at the top of the head, which was accomplished by heating the base of the rail The numerals affixed to the fourth figure of the diagram show the values of the gauged lengths after the base had been heated over its full length and width The differences between the results entered on the third and fourth figures of the diagram show the amounts which heating the base of the rail had increased the gauged lengths on the top of the head These amounts were 0 0022, 0 0031, and 0 0037 inch, respectively Thus it is shown that heating the fibers most remote from the neutral axis on one side results in lengthening the remote fibers on the opposite side of the rail The same results in kind were obtained on a chilled iron car wheel by locally heating the rim with a torch

The head of this rail was next heated to about 1,500° F and the upper surface quenched in water This increased the length of the top of the head, while shortening the gauged lengths at the fillets The metal of the head rotated about a secondary neutral axis, above which the metal was lengthened, below which it was shortened Secondary neutral axes are introduced in rails by the acquisition of internal strains, which modify the intensity of the stresses along different elements under bending loads Until the elastic limit of some portion of the cross section is exceeded the behavior of the rail as a whole remains unchanged, however, with respect to its section modulus, or moment of inertia The internal strains which cause the introduction of secondary neutral axes, however, exert an influence on the elastic limit of the rail taken as a beam, generally lowering its value Such results emphasize the need of giving consideration to the subject of internal strains, as they are descriptive and explanatory of common causes which affect rails when in the track

The head of rail No 15 was next detached from the web and base, which was attended with further expansion of the upper surface while the under side contracted still more The strains displayed at this time are those which may properly be converted into corresponding stresses The gauged lengths in the fillets contracted 0 0214 and 0 0193 inch, respectively, representing the relief of strains of tension equivalent to 64,200 and 57,900 pounds per square inch At the top of the head the strains released were 0 0201, 0 0226, and 0 0218 inch, respectively These were strains of compression, and are equivalent to stresses of 60 300, 67,800 and 65 400 pounds per square inch As great as these internal strains appear they were not yet fully released Residual strains still remained in the metal as shown when the head was detached from the web

The head was next reduced in depth and subsequently channeled The strains and their equivalent stresses along the top of the head as finally released were as follows Strains, 0 0242, 0 0269, and 0 0262 inch, stresses, 72,600, 80,700, and 78 600 pounds per square inch These stresses may be mentally compared with 16,000 pounds per square inch, the ordinary limit of stresses for permanent structures in conservative engineering practice These intense stresses were introduced by means of special treatment of the rail The operations performed however, represent in kind and also in degree those which rails experience They were carried out on a larger scale than those in the track, merely to have a sufficient length of rail section and volume of affected metal on which to acquire numerical values In the track, local strains of great intensity doubtless exist, not incomparable with those displayed by these experimental sections

Diagram No 7 shows the successive changes in lengths which the channeled sections displayed when box annealed in lime at 1,400° F, and when reheated and quenched in tepid brine from a temperature of 1,400° F The figures entered on this diagram are differences in lengths taken from diagrams Nos 1, 3, and 4, which give the total changes in lengths of the sections at each stage As previously stated in describing the rail sections individually, the process of annealing shortens the sections on each of the gauged lengths the operation of hardening lengthens the sections

The mean contraction in length due to annealing, on the 20 gauged lengths here represented was 0 0017 inch, the mean expansion on the 10 gauged lengths when heated and quenched was 0 0235 inch The equivalent stresses are 5,100 and 70 500 pounds per square inch, respectively The annealing of one portion of the cross section of a rail and the hardening of another portion set up large opposing internal strains as these results indicate

Strain gauge measurements were made on the flanges of some of the rails in addition to those on the heads The shaded areas of the flanges of the second figure of diagram No 3 show the positions of the strips which were examined The relief of internal strains at this stage represents the cooling strains of fabrication Service conditions do not as a rule disturb the primitive cooling strains in the flanges, a circumstance which indicates that this part of the cross section of a rail is not ordinarily subjected to overstraining forces This remark refers to longitudinal strains at the edges of the flanges and not to crosswise stresses at the middle of the width of the base The latter place is not immune from stresses which lead to rupture, as the origins of crescent-shaped base failures demonstrate

The internal strains in the strips taken from the edges of the flanges of rail C were equivalent to 9 900 and 11,400 pounds per square inch compression, which are ordinary values for thick-flanged bases On one of the strips, gauged lengths were established on each of its four sides, after which it was hardened It was heated to about 1,500° F and quenched in water, resulting in intense hardness of the metal The strip expanded on each gauged length in a very pronounced degree The average expansion was 0 0347 inch in 10 inches To reduce the strip to its former length would require a force of compression of 104,100 pounds per square inch Since the elastic limit of hardened steel, in compression, is very high, it is permissible to make this comparison between the expansion of the strip the result of hardening and the mechanical force necessary to restore it to its former length

The slight recovery in length experienced by hardened steel which takes place soon after quenching has already been referred to This strip and one from rail D afforded further examples of this shrinkage which hardened steel displays After a rest of 17 hours the present strip was found to have contracted in length 0 0004 inch, which was increased to 0 0006 inch after the lapse of 40 hours Reexamined after 88 hours, no further contraction was found This creep of the steel corresponds to a stress of 1,800 pounds per square inch

The instability of hardened steel in reference to maintaining fixed dimensions is also shown when exposed to higher temperatures

This flange strip was heated in a water bath for one hour at 192° F., whereupon it showed a permanent contraction when cold of 0.0016 inch. The equivalent stress is 4,800 pounds per square inch. Further contraction was displayed when exposed to higher temperatures. After heating to 500° F. and cooling, the successive decrement in length was 0.0079 inch. The equivalent stress is 23,700 pounds per square inch. Upon heating to a temperature approximately 1,200° F. a further contraction of 0.0116 inch took place. The total contraction of the hardened strip, the effects of exposure to higher temperatures, including the early creeping, was 0.0217 inch, the equivalent stress of which is 65,100 pounds per square inch.

The behavior of the flanges of rail D was the same as those of rail C. The primitive strains in the two strips were equivalent to 6,300 and 11,400 pounds per square inch, each of compression. One of the strips was hardened in the same manner as that of rail C. It displayed an average expansion in length of 0.0291 inch. The stress corresponding to this strain is 87,300 pounds per square inch. The creeping of this strip 17 hours after hardening was 0.0006 inch, which was increased to 0.0010 inch at the expiration of 40 hours. Again observed after 88 hours rest, a slight additional recovery appeared to have taken place, 0.0002 inch, making the total creep 0.0012 inch. This amount is equivalent to 3,600 pounds per square inch.

When raised to higher temperatures this strip displayed the same characteristics as the preceding one. Heated to 192° F. and cooled, the contraction was 0.0011 inch. After it was raised to 500° F. the successive decrement was 0.0086 inch and after heating to approximately 1,200° F. the additional contraction was 0.0132 inch. The total contraction, due to both heating and creeping, was 0.0241 inch, the equivalent stress being 72,300 pounds per square inch.

The presentation of so many figures representing numerical values may seem unnecessary and wearisome. The importance which attaches to them, however, justifies their introduction. They represent internal forces which are common to wheel-burnt rails, and phases in the behavior of rails which should be familiar to all. High wheel loads are destructive agencies even when rolling loads only are concerned. Their destructive influences are enhanced when slipping of the wheels occurs. On some rails only abrasive wear is the visible result, while others plainly exhibit the effects of wheel burning. The present investigation furnishes evidence that many rails are affected by wheel burning, the effects of which are obscure and escape notice, or the surface indications may have been effaced by the action of subsequent wheels.

In brief résumé, the conditions of service are such that all wheels under present equipment introduce cold-rolling strains in the heads of the rails A state of mechanical hardness is acquired in the cold-rolled zone The ductility of the steel is exhausted as the result of cold rolling

The slipping of wheels is attended with the generation of intense heat as the sparks emitted show This intense heating is local and confined to a limited zone of surface metal The colder metal of the interior of the head acts as a quenching medium, abstracts the heat by conductivity, and hardens the surface film The hardened surface is devoid of ductility This is characteristic of thermal hardness

Steel embrittled by mechanical hardness commonly retains some residual ductility which it displays under the impinging pressures of the wheels, although it is incapable of further flow under tensile stresses Thermally hardened steel retains no residual ductility This constitutes the difference between the two states of hardness and is an important feature to bear in mind in considering wheel-burnt rails This distinguishing difference is the feature which accounts for the manner of failure of the present rail A shallow hardened zone was presented incapable of flow under wheel pressures, and of insufficient depth to support and distribute the impinging pressures of the wheels Surface cracks were formed, some of which under the alternate directions of the tractive forces of the driving wheels of the engine and the resistance of the wheels of the train penetrated the head, weakened the rail under bending stresses and culminated in rupture

This investigation of special rail sections on the elementary features involved in wheel burnings, embracing the phenomena attending heating, quenching, and annealing of steel, shows how the introduction of intense internal strains may come about These phenomena may reasonably be held to have exerted an influence on the formation of the series of surface cracks which eventually caused this rail to break

The broken rail presented surface indications of impaired integrity in the fine hair lines of the series of short crosswise cracks, the significance of which now appears The approach to rupture in steel in service is not signalized by visible manifestations The actual separation of the metal is practically the first warning given by the steel itself All wheel-burnt rails are a source of anxiety, but since they are numbered by thousands which do not break in the track, it becomes a matter of judgment when they should be removed One of the objects of the present investigation is to point out and explain the nature of the complex conditions which are involved in such cases It is obvious on every hand that rails are overstrained members, the great source of injury being the intensity of the impinging pressures between the tread of the wheel and the running surface of the head of the rail Reduction of wheel loads means increased safety, increase of wheel loads means the more rapid exhaustion of the primitive margin in safety, shortening the life of the rail and increase in the elements of danger

SUMMARY

The wheel burning of rails, in some degree, is a matter of common occurrence in many places in the track Rails in this condition abound in yards, freight terminals, and in the vicinity of signal towers and stations Few, if any, of these localities are free from examples of rails which are thus affected

The present derailment was due to the failure of a rail which broke at several places along its length, exhibiting incipient cracks in the head Investigation by the engineer-physicist showed these cracks to have had a thermal origin That is this was a wheel-burnt rail, although its appearance in the track was not suggestive of such action having taken place There was a series of fine crosswise cracks visible on the running surface of the head near the gauge side, but the usual evidence of wheel burning, a roughened abraded surface was not shown

Sections of the rail were pickled in hot hydrochloric acid This exposure and the microscopic examination conducted each revealed the effects of wheel burning The rail had been exposed superficially to a high temperature and hardening had resulted therefrom Incipient cracks were developed in the thin layer of hardened steel, some of which had penetrated the normal metal of the rail These incipient cracks greatly weakened the rail and led to its premature failure This type of wheel burning is one of peculiar danger

The series of short crosswise cracks was not conspicuously shown They were noticeable, however because they did not present the usual characteristics of flow of metal under wheel pressures Their full significance now appears in the results of the investigation of the rail They stand as warning indications of the seriousness of their presence

In cases of wheel burning, profound changes take place in the structural state of the steel, changes which take place within extremely narrow limits Rapid transition from one phase to another so narrowly confined may in itself intensify the internal destructive forces Special tests were made to illustrate the phases in detail which the hardened zones experience, the results of which are embodied herein The destructive influences which prevail are clearly shown, and they constitute elements of danger in the track

The prevention of wheel burning in its entirety presents great practical difficulties Efforts should be directed toward minimizing these destructive influences The presence of incipient cracks as they were displayed by this rail is evidence of impaired strength and constitutes a warning signal that a dangerous state has been reached

Respectfully submitted,

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Chief, Bureau of Safety

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