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DEPARTMENT OF COMMERCE
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EFFECT OF SULPHUR AND PHOSPHORUS ON IRON AND STEEL

1872 Bell, I. L. — Chemical Phenomena of Iron Smelting, Conclusions, Journal of Iron and Steel Institute, 1, p. 88.

Refers to Bessemer process as freeing iron of nearly all impurities but P. and perhaps this will be accomplished.

1872 Pearse, J. B. — The Manufacture of Iron and Steel Rails, Trans. A.I.M.E. 1, p. 162.

A consideration of the important qualities of steel and the proper tests to show their uniformity. P and Mn produce brittle rails. In fact, no good steel has ever been made with more than 0.2% P.

1873 Bell, I. L. — President's address at annual meeting of Iron and Steel Institute, Journal of Iron and Steel Institute. 1, p. 1,

States that C and P can be combined with iron but M. Euverte of Terrenoire has raised the question whether it is not the concurrent presence of these elements which exercise so fatal an effect on the quality of steel. This French metallurgist does not believe the presence of phosphorus in moderate quantities will interfere with the malleability of wrought iron. On p. 38, idem, he says silicon, phosphorus and sulphur injure the metal.

1874 Raymond, R. W. Phosphorus and Carbon in Iron and Steel, Trans. A.I.M.E., 3, p. 131,

Introducing data to show that P may be increased without injury to steel if the amount of C is proportionately decreased and that this fact has been known for some time.

1876 Dyer, B. Chemical Analysis Considered in Its Application to Civil and Mechanical Engineering, Jour. of Iron and Steel Institute, p.507.

Abstract. Touches upon the influence of minute proportions of P & S upon the quality of iron and steel.

1877 Siemens, Dr. President's Address, - Journal of Iron and Steel Institute, p. 6.

The use of Mn without C neutralizes the objectionable P so long as the latter does not exceed 0.25%. This metal in which P takes the place of C is extremely ductile when cold.

1878 Adamson, D. On the Mechanical and Other Properties of Iron and Steel, Journal of Iron and Steel Institute. p. 383.

Concludes that a higher endurance of drifting test is secured by the lowest amount of S and P. Hot bend tests also depend on absence of S. while the P must also be low.

1878 Bell, I. L. On the Separation of Phosphorus from Pig Iron, Journal of Iron and Steel Institute, p. 17.

"The weakening effect of phosphorus on the quality of iron or steel containing this substance has been acknowledged for many years." In the discussion, Mr. Edward Riley said he examined some steel rails which contained 0.242 percent P. and 0.34 percent C. He believed "we could do with considerably more than 0.10 per-cent, the limit fixed by some" for steel rails.

1878 Dudley, C. B. The Chemical Composition and Physical Qualities of Steel Rails, Trans. A.I.M.E., 7, p. 172.

Cannot find that S. is anywhere said to have a deleterious effect on the wear of a rail while he finds some metallurgists claim it is an advantage. P. however, is classed as a "hardener". Urges a strict upper limit of 0.10 percent for P. content. Discussion: G. J. Snelus, Jour. Iron and Steel Institute, p. 582, 1882,(2). Presents data of varying chemical composition for steel rails but the general conclusion is that the chemical composition is quite unconnected with the cause of their failure.

1878 Marche, M. E. On Certain Matters Affecting the Use of Steel, Jour. Iron Steel Institute, p.404.

Reviews many tests and concludes that the effect of P, Si, etc. on the properties of steel is not definitely known.

1878 Troost, and Hautefeuille Sulphur and Phosphorus in Iron, Abstract; Journal Iron and Steel Institute p.252,

Showed that small quantities of S and P combined with iron do not destroy its metallic lustre but alter its malleability and ductility considerably.

1879 Brown, R. On the Neutralization of Phosphorus in Steel and Steel Like Metals, Jour. Iron Steel Institute, p. 355.

Says a large percentage of P. in iron makes it cold short. Castings with the P. content neutralized are very solid and free from blow holes.

1879	Deshayes, V.	Note sur les Raports Existant entre la Composition Chimique et les Proprietes Méchaniques des Aciers. Annales des Mines, 15, p. 326. Sulphur makes steel non-homogeneous and diminishes its elongation. P does not diminish the elongation and increases the breaking strength.
1879	Williams, E.	President's Address, Jour. Iron and Steel Institute, p. 8. States that the first Bessemer rail contained 0.446% P. "quantity that would frighten us in these days" but carbon and silicon were almost absent.
1880	Mushet, R. F.	The Dephosphorization of Iron, Jour. Iron and Steel Institute, 1, p. 229. A summary of the literature on this subject to date, showing the desire to eliminate the P and belief of its injurious effect.
1880	Riley, E.	Discussion: The dephosphorization of iron, Jour. Iron and Steel Inst. p. 571. Says some of the best steel rails contain from 0.10 to 0.18% S. Rails containing 0.27% S had stood all mechanical tests.
1882	Müller, F.C.G.	Properties of Steel in Relation to Its Chemical Composition, Abstract, Jour. Iron and Steel Institute, p. 371. Phosphorus, ever since its discovery in iron, has been recognized as an enemy of steel. In large quantities it produces cold shortness. Gives experimental results of comparative properties of carbon and phosphorus steels. Considers that if sulfur is below 2% it is not detrimental to the quality of steel.

1882 Wasum, A. Copper and Sulfur in Steel, Stahl und Eisen, 2, p. 193.

Considers 0.10% S as perfectly innocuous and 0.15 or 0.16 as the limit at which red shortness may be expected.

1885 Editorial. The Rolling Qualities of High Phosphorus Steel, Iron Age, 36, No. 3, p. 1.

Steel of 0.318 P, 0.10 C, and 0.047 S rolled very well. Experiments at Edgar Thomson Steel Works.

1887 Howe, H. M. Sulfur in Steel Rails, Engineering and Mining Journal, 43, p. 459.

Sulfur makes iron brittle at red heat and destroys its welding power. Gives compositions of rails. Says rails with sulfur content above 0.18% are very rare.

1889 Baker, M. File Steel, Abstract, Journal of Iron and Steel Institute, 1, p. 374.

The value of tool steel varies inversely with the phosphorus content, which should never exceed 0.04 percent P.

1890 Dudley, C.B. The Wear of Metal as Influenced by Its Chemical and Physical Properties, Jour. Iron and Steel Institute, 2, p. 250.

Finds, in general, high P. content is bad for wearing qualities.

1890 Sandberg, C.P. Rails, Institution of Mechanical Engineers Proc. p. 301.

Rails should be as hard as is consistent with safety. Gives composition of Russian rails. Good ones had 0.11% P. while poor had 0.19% P. Si should be low when P and C are high.

1892 Stead, J.E. On the Elimination of Sulfur from Iron, Jour. Iron and Steel Institute, 2, p. 223; Engineering and Mining Journal 54, p. 364, 1892; 56, p. 595, 1893.

Discusses how S gets into pig iron, the effect of puddling, and its elimination by various processes.

1892 Webster, W. R. Observations on the relations between the chemical constitution and physical properties of steel, Trans. A.I.M.E. 21, p. 766.

Tests on steel with C limits 0.07 to 0.18%. P increases tensile strength 800 lb. per 0.01% P at 0.07% C and 1500 lb. per 0.01%P. in.15% C.

1893 Dudley, P.H. Manufacture and Service of Steel Rails, Engineering News, 30, p. 172.

Abstract of paper giving the effect of different chemical elements in steel rails and their proper proportion in order to give toughness. Sulphur and P. are two impurities which are very objectionable. S. makes the steel red short; P. increases the size of the crystallization and makes the metal brittle and liable to break in cold weather.

1893 Koch, W.E. Williams, F. H. Segregation in Steel.- Engineering Society of Western Pennsylvania, Feb. p. 23, Mar. p. 15.

Determination of P and S in steel and pig iron and probable cause and remedy of segregation.

1893 Langley, W. J. Physical Properties of Steel as Related to Its Composition and Structure, Jour. of Association of Engineering Societies, 12, p. 189.

Results of numerous investigations on the influence of various elements in steel and physical properties of steel including tempering and recoalescence.

1893 Metcalf, Wm. Chemical and Physical Properties of Steel, Engineering Record, 27, p. 154.

Abstract of remarks on annealing and hardening of structural steel. Both P and S are wholly detrimental, especially in high carbon steel.

1896 Thompson, F.E. Sulfur in Mild Steel, Jour. Iron and Steel Inst. 49 (1) p. 450; Iron Age, 57, p. 810, 1896.

The writer first briefly reviews previous investigations and then shows the treatment of S in the basic converter and in basic open hearth furnace, giving a large number of analyses, tests, and other data.

1896 von Dormus, A.R. Why do Rails Break? Railway Magazine, May 8.

Discussion of chemical physical and etching tests, urging the importance of the last named. The great differences in strength are attributed to segregations in the ingots and the suggestion is made that main track rails be selected from the lower 2/3 of rolled beams only.

1896 Campbell, E.D. On the Diffusion of Sulphides Through Steel, American Chemical Journal, 18, p. 707.

Describes experiments selected from 40 diffusion tests, giving possible explanation of observed phenomena. Since the oxysulphide of iron at a high temperature is an extremely mobile fluid, it will rapidly diffuse through the pores of the steel and be absorbed by the lining.

1896 Campbell, E.D. Babcock, C.S. On the Influence of Heat Treatment and Carbon Upon the Solubility of Phosphorus in Steels, American Chemical Journal, 18, p. 719.

With very low percentage of carbon, the effect of heat treatment upon the solubility of P. is slight. With increase of C. the effect of hardening is to diminish the solubility of P. With high percentage of C. the solubility is increased by slow cooling.

1897 Cunningham, A.C. The Relation of Tensile Strength to Composition in Structural Steel, Papers American Society of Civil Engineers, 23, p. 232.

A brief account of notable investigations made of late years with the conclusions of Mr. H. H. Campbell with rule adopted by the author.

1897 Landis, H.K. Tensile Strength of Steel, American Manufacturing and Iron World, July 30.

Discusses the influences that affect the strength of steel, and presents equations, the results of a large number of tests.

1897 Rhead, E.L. The Occurence of Sulfur in Iron. Its Introduction and Removal, American Manufacturer and Iron World, April 2.

Deals mainly with a mass of evidence accumulated by many workers and as far as possible reduces it to order.

1898 Moxham, A. J. Composition of Steel Rails to Insure Maximum Resistance to Wear, Engineering News, 40, p. 180.

Desiderata for street railway rails. From his tests he concludes it is justifiable to pay extra for low P rails but adds "there is some doubt after all as to the advantages to be gained from the use of low P steel".

1898 von Dormus, A.R. Weitere Studien uber Schienenstahl Zeitsche.d.Oesten Ing. u.Arch.Ver. 50, p.665.

A very full investigation into the use of basic open-hearth steel for rails, with data and results of tests, micrographs of etched sections and diagrams of behavior in service.

1898 Webster, W.R. The Relations Between the Chemical Constitution and the Physical Character of Steel, Trans. A.I.M.E. 28, p. 618.

Investigation concerning the tensile strength of steel, quoting from the various authorities and giving the results from the writer's investigations.

1898 West, T.D. Effects of Phosphorus on the Strength and Fusibility of Iron, Engineering, 65, p.694.

By pouring Bessemer steel on sticks of phosphorus, he increased the strength of the iron from 25% to 75%. The fusibility was also greatly increased. Gives comparative tensile tests, transverse tests and chemical compositions.

1900 Editorial Brittle Rails and Phosphorus Content, Railroad Gazette. 44, p. 202.

Discussion of complaints and of the cause of the trouble. Too hot finishing of rails is as bad as high P. content.

1900 Schneider Specifications for Rolled Steel, American Railway Engineering Association, 3, p.242.

Letter from Mr. Schneider, American Bridge Company, advises not to specify S content as the mills will keep it down in order to aid rolling.

1900 Stead, J. E. Iron and Phosphorus, Jour. Iron and Steel Institute, 58, (2), p. 60; Metallographist 4, p.89,1901; Engineering, 70, p. 512,

An account of researches on chemical compounds of Fe and P and report of results of much interest. Metals of his first class contain from a trace of P to 17%. The grains become large as the P increases and the hardness steadily increases with the proportion of Fe_3P in solid solution.

1900 Webster, W.R. Rail Steel- Its Chemistry and Heat Treatment, Railroad Gazette, 44, p. 99.

A contribution to the problem of the relations between the chemical constitution and physical properties of steel.

1901 Arnold, J. O. The Properties of Steel Castings, Journal Iron and Steel Institute, 59, p. 175.

Cause of brittleness in a steel casting was found to be brown lines running through the ferrite, made up of sulphide.

1901 Bricka The Quality of Steel for Rails, Engineering News. 45, p. 173.

A discussion of the relative importance of chemical specifications for European rails.

1901 Fay, Henry Segregation of Phosphorus in a Piece of Cold-Rolled Shafting, Metallographist, 4, p.115.

An illustrated report of an examination, microscopically and chemically of a broken shaft showing an interesting case of segregation.

1901 Wahlberg, Alex. Brinell's Method of Determining Hardness and Other Properties of Iron and Steel, Journal Iron and Steel Institute, 60, (2), p.234.

Steel containing .56% Sulfur along with 1.06% manganese can be easily rolled and the mechanical properties of this metal when tested in the direction of rolling are at least equal to those of a steel with about the same carbon content but containing low sulfur. A 0.15% sulfur steel gave best results on impact tests.

1902 Andrews, T. Effect of Segregation on the Strength of Steel Rails, Iron and Coal Trades Review, 65, p. 1166.

Investigations showing the extent of segregation of combined carbon and other elements, the effect, giving typical examples. S. and P. appear to have the greatest tendency to segregation.

1902 Houghton, S.A. The Internal Structure of Iron and Steel With Special Reference to Defective Material, Metallographist, 4, p. 256.

Shows that chemical analysis is not all that is needed in determining the quality of metals, and that an examination of the structure is of great importance. Considers the causes of failure.

1902 Job, R. Steel Rails: Relation Between Structure and Durability, Journal Franklin Institute, 154, p. 17.

A report of investigations to determine qualities which resulted in fractures, or in rapid wear in service and to find the means to reduce these to a minimum. Mentions variation of chemical composition in both good and bad rails.

1903 Arnold, J.O. Waterhouse, G.B. The Influence of Sulphur and Manganese on Iron, Journal of Iron and Steel Institute, 63, p. 136; Iron and Coal Trades Review, 66, p. 1275.

The sulphide of iron is deadly in its effect upon steel while the sulphide of manganese is comparatively harmless. Discussion.

1904 1905 Campbell, H.H. The Influence of Carbon, Phosphorus, Manganese and Sulphur on the Tensile Strength of Open Hearth Steel, Journal of Iron and Steel Institute. 66, p. 21, 1904-II; Revue de Metallurgie 2 bis, p. 77.

Gives an account of investigations made at the works of the Pennsylvania Steel Co., Stulton, Pa. P increases tensile strength of steels while S. weakens it to a slight extent in acid steel but strengthens it to a slight extent in basic steel.

1904 Churchill, C.S. Report of Committee IV. Rail Discussion, American Railway Engineering Association, 5, p. 478.

He says "I have kept record of the breaking of rails on our road and for several years. In no case have I found a broken rail due to the chemical analysis."

1904 LeChatelier, H. The Brittleness of Steel, Iron and Steel Met. 7, p. 125.

Remarks on the intermittent brittleness of steel, the causes, etc., discussing the nature of the metal, external conditions and tests. P and S render steel brittle.

1904 Stead, J.E. The Segregatory and Migratory Habit of Solids in Alloys and in Steel Below the Critical Points, Iron and Steel Met. 7, p. 139.

An illustrated study with the conclusions reached that certain temperatures near to, but below, the eutectic point of the iron-phosphorus eutectic, the two constituents when quite solid are capable of migrating from one part to another.

1904 Wüst, F. Schlosser, P. Der Einfluss von Kohlenstoff, Silizium Mangan, Schwefel, und Phosphor auf die Bildung der Temperkohle in Eisen, Stahl und Eisen, 24, p. 1120.

Data and results of tests showing the influence of the various constituents. Manganese opposes the formation of graphite; sulphur still more checks its formation; phosphorus has apparently no effect.

1905 Hunt, R.W. Manufacture of Bessemer Steels, American Railway Engineering Association, 6, p. 179.

Tests on 13 English rails laid in America that have given excellent service. After several years service, they were analyzed. Showed S from 0.05 - 0.155 and P from 0.077 - 0.156. "Chemically a bad lot but physically most excellent."

1905 Job, R. Some Causes of Failures of Rails in Service, Railroad Gazette, 50, p. 12.

Gives the causes brought out by extensive investigations of rail failures made by the Philadelphia and Reading. It was found that composition had nothing to do with the rail failures. This is due to unsoundness in the metal.

1905 Konkelino, K. Le Phosphore dit Misible, Revue de Metallurgie, 2 bis p. 256.

1905 Longmuir, P. Steel Castings and the Constitution of Steel, Foundry, 27, p. 72.

On the effect of carbon, Mn., Si., S. and P.

1905 Thomas, F.M. Properties of Steel, Mechanical Engineer, 16, p. 335.

Considers the properties of commercial steels and the effects produced by various modifications in chemical composition and treatment.

1907 Houdard Solubilite du Carbone dans le Sulfure de Manganese, Revue de Metallurgie, 4 bis. p. 657.

1907 Howe, H.M. Behavior of C and P in Steel, Engineering and Mining Journal, 83, p. 1087.

A discussion of J. E. Steads' explanation of the banding of carbon and phosphorus and the theory of incompatibility.

1907 Howe, H.M. Does the Removal of Sulfur and Phosphorus Lessen the Segregation of Carbon? Proc. of Am. Soc. Test. Materials. 7, p. 75.

Presents data from a hundred cases of segregation. Finds no evidence to show that either low sulfur or low phosphorus content tends to restrain segregation but rather it seems to aggravate that segregation.

1907 Law, E. F. The Non-Metallic Impurities in Steel, Journal of Iron and Steel Institute, 74, p.94.

Gives results of observations considering sulfide of iron, sulfide of Mn. etc. discussing their effects. Manganese sulfide seems less injurious than other elements. If, however, it segregates it may have a very injurious effect on the steel.

1908 Coes, H. V. Steel Rail Breakages, Questions of Design and Specifications, Engineering Magazine, 35, p. 417.

A comparison of views of maker and consumer as to the causes. The contentions seem to be as to the P. and the shape of rail section. "There is no doubt that the P. content must be decreased as the C. increases in order to prevent brittleness in the rails."

1908 de Kryloff, M.J. Contribution a l'Etude des Aciers Phosphoseux, Revue de Metal. 5, p. 355.

A metallographic study of the effects of various amounts of P on the properties of steel.

1908 Fay, Henry Manganese Sulphide as a Source of Danger, Engineering News, 60, p. 94.

On examining some failed rails, he found manganese sulphide in a segregated form. To eliminate it, the sulphur content must be low. Also, if the metal is allowed to stand a longer time after the addition of ferro-manganese, this sulphide will rise and may be skimmed off.

1908 Levy, D.M. Iron, Carbon and Sulfur, Journal of Iron and Steel Institute, 77, p. 33.

Reports of a research made to investigate the action of S as it affected the relations of iron and carbon. A comprehensive review of previous work. Gives Bibliography.

1908 Saklatwalla, B. Constitution of Iron and Phosphorus Compounds, Journal Iron and Steel Institute, 77, p. 92.

A complete thermal and metallographic investigation of the subject.

1908 Wüst, F. Beitrag zum Einfluss des Phosphors auf das System Eisen-Kohlenstoff, Metallurgie 5, p. 74; Revue de Metal. 5 bis p. 403.

The temperature at which saturated iron-carbon begins to solidify is decreased by the addition of phosphorus. By the addition of phosphorus a new recoalescence point appears at 950 degrees C.

1909 Crowe, Edward. Corrosion of Iron and Steel, Engineer, 107, p. 431.

His investigations show phosphorus is a powerful antidote to corrosion. Steel immersed in sea water corrodes inversely in proportion to its phosphorus content.

1909 Huntly, G.N. Sulfur as a Cause of Corrosion in Steel, Journal of Society of Chemical Industries, 28, p. 339; Engineer 107, p. 417.

Finds that streaks of manganese sulfide are found along cracks in boiler plate caused by corrosion. The sulfur content is to blame for this corrosion.

1909 Ziegler, M. Recherches sur des alliages du Fer avec la Soufre, Revue de Metal 6, p. 459.

An exhaustive metallographic and chemical study.

1910 Churchill, C.S. Characteristic Rail Failures, American Railway Engineering Association. 11-1, p. 387.

Photographs, chemical analyses and classification of failure. Over 50 failures classified; six caused by high P and C, three by too soft material. Others due to poor manufacture as pipe, segregation, flaw, unwelded seam, etc., 81 Open Hearth rails on Illinois Central failed out of 2660 in one month. Carbon 0.06 and phosphorus 0.04 too high.

1910 Churchill, C.S. Chemical and Physical Tests of Rails, American Railway Engineering Association, 11-1, p.454.

Drop, tensile tests and chemical analyses. No conclusions given.

1910 Cushing, W. C. Rail Failure Statistics for Year Ending October 31, American Railway Engineering Association, 13, p. 613, 1912.

Tabulation showed large differences sufficient to overcome differences in rail sections. Comparison Bessemer vs open-hearth rails.

1910 Konstantinow, N. The Iron Phosphorus System, Zeitschr. fur anorg, Chem. 66, p. 209.

The cooling curves of 30 alloys of iron and phosphorus were investigated. P varied from 1/2% to 21%. The existence of Fe_3P and Fe_2P is confirmed.

1910 Levy, D. M. The Influence of Manganese Sulphide on Iron and Steel, Iron Trade Review, 46, p. 433.

Gives results of investigation on the presence of manganese sulphide. Does not always exist pure. Recommends an excess of Mn.

1910 Liesching, Theodor. Uber den Einfluss des Schwefel auf das System Eisen-Kohlenstoff, Metallurgie 7, p. 565.

The freezing point is lowered with higher sulfur content while the pearlite point remains stationary at 700 degrees.

1911 Churchill, C.S. Drop Tests on Rails, American Railway Engineering Association, 12-2, p.188.

Statement of drop tests and chemical analyses of rails rolled for the Norfolk and Western. Gives results of various heights of rails of known composition and a comparison of rail analysis with mill analysis.

1911 Coroner, Report by, Rail Failure-Lehigh Valley Wreck, Manchester, N. Y., Iron Trade Review, 49, p. 1108.

Describes the history of the "A" open hearth rail and how it broke. Says rail contained a pipe and a transverse fissure. Was cause of a wreck. Professor Touceda made a chemical analysis and found all elements O.K. except manganese which was 1.21 percent, so high as to cause cold shortness under impact.

1911 Cushing, W.C. A Study of 40 Failed Rails, American Railway Engineering Association, 12-2, p.230.

A report of examination of 40 failed rails, mostly Bessemer which failed in the main tracks of the S.W. system of the Pennsylvania. Indicates that failures classified as crushed and split heads were confined mostly to rails of segregated metal from the upper part of the ingot.

1911 Cushing, W.C. A Study of 68 Failed Rails, American Railway Engineering Association, 12-2, p.293.

Show split heads usually occur in segregated metal. The type "broken" rail in a large proportion of cases showed metal satisfactory on analysis and tensile tests and the work did not bring out the cause of failure.

1911 Dudley, P.H. Ductility in Rail Steel, Railway and Engineering Review. 51, p. 604.

Discusses the effects of the different constituents of iron, temperature, etc. P. reduces the capacity of the metal to distribute rapid strains or those of large magnitude before fracture occurs. Sulphur is an impurity and renders the metal cold short.

1911 Wickhorst, M.H. Investigation of a Split Head Rail, American Railway Engineering Association. 12-2, p. 469.

Results of examination of a split head rail by means of analyses, tensile tests, microscopic tests and numerous sections.

1911 Wickhorst, M.H. Tests of Bessemer Rails, Edgar Thomson Works, Carnegie Steel Company, American Railway Engineering Association, 12-2, p. 448.

Results of analyses, etching, tensile, drop, slow, bend tests.

1911 Wickhorst, M.H. Tests of Bessemer Rails, Illinois Steel Company, American Railway Engineering Association, 12-2, p. 413.

Results of analyses, etching tensile tests, drop and slow bending, made at South Chicago.

1911 Wickhorst, M. H. Tests of Open Hearth Rails at Gary, American Railway Engineering Association, 12-2, p. 428.

Results of analyses, etchings, tensile, drop, slow bend tests.

1911 Wickhorst, M.H. Tests of Titanium Bessemer Rails, Lackawanna Steel Company, American Railway Engineering Association, 12-2, p.399.

Results of analyses, etching, tensile and drop and bending tests of titanium treated steel rails made by Lackawanna Company.

1912 Cushing, W.C. The Question of Improvement of Rail Design and Specifications from 1893 to date, American Railway Engineering Association. 13, p. 843.

Discusses "Effect of Temperature of Rolling," "Standard Methods of Testing," "Effect of Chemical Properties","Physical Properties," "Details of Manufacture" and "The Work of Mr. Wickhorst to Date."

1912 LaBach, P.M. Comparison of Chemical Constituents of Steel Rails from 1870 to Date, Railway Age Gazette, 532, p. 684.

Gives tabulated data with references to the chemical contents of rails rolled up to the present time, with conclusions.

1912 Trimble and Cushing — A Study of 17 Good Service Rails, American Railway Engineering Association, 13, p. 573.

The results given of the laboratory examination of some rails that had been in service a long time. Analyses, tensile tests and microphotos. While most of the rails showed good laboratory results, some were rather high in phosphorus.

1913 Hatfield, W.H. — Influence of Sulfur on the Stability of Iron Carbide in the Presence of Silicon, Journal of Iron and Steel Institute, 87, p. 1[illegible].

Sulfur increases the stability of iron carbide at high temperatures. Silicon and manganese neutralize the influence of sulfur.

1913 Steinberg — Uber schwefelhaltige Einschlüsse in Stahl, Journal der russ. Met. Ges. p. 514.

The sulfur content separates out from liquid steel by crystallization. It is only soluble in the liquid and not in the solid steel.

1915 Arnold, J.O. Bolsover, G.R. — Supplementary Notes on the Forms in Which Sulphides may Exist in Steel Ingots, Iron and Steel Institute, p. 271

Discusses effect of Al on segregation.

1915 Hatfield, W.H. — Phosphorus in Iron and Steel, Engineer, p. 120, 1916, p.335; Iron Age 96, p.1234; Journal of Iron and Steel Institute, 92, p.122.

Concludes 0.20% P may be present in certain alloys without unduly modifying the physical properties of the heat treated materials.

1915 Johnson, J.E.Jr. Recent Developments in Cast Iron Manufacture, Journal Franklin Institute, 179, p. 59, 171.

Deals with recent developments in the manufacture of cast iron and discusses the effects of various elements on the properties of cast iron. Sulfur is the most troublesome element in the metallurgy of steel while P increases the fluidity of cast iron and its effect up to 0.40% seems to increase the strength.

1915 Pitman, R.A. Blowholes and Sulfur, Foundry 43, p.95.

Poor pouring and not the S content is to blame for blowholes.

1915 Schipper, J.E. Steel: Its Pathology, Automobile, 32, p.611.

Deals with composition, Iron, carbon, manganese and other impurities always present. Lists S as a "strength sapper and P as a "weak link."

1915 Stead, J.E. Iron, Carbon and Phosphorus, Journal of Iron and Steel Institute, 91, p.140.

Deals with the distribution of P in steel and the mechanical properties of phosphoritic-carbon steels and new methods for detecting variations of P in iron and steel.

1915 Thompson, A.W.T. Gagging Rails and Transverse Fissures, Railway Age Gazette 59, p.888.

Does not think transverse fissures are caused by gagging for these fissures are seldom found except in open hearth low phosphorus high carbon Bessemer rails.

1915 Wickhorst, M.H. Failures-Rail for,- American Railway Engineering Association, 18, p. 923, 1917.

Statistics for 1915 covering open hearth versus Bessemer, comparing causes, comparing mills.

1915 Wickhorst, H.M. — Study of a Rail with Internal Fissures, American Railway Engineering Association, 16, p. 195.

Note: "C" does not mean carbon here.

Study of a broken O.H. rail after four years service, a "C" rail. Chemical and microscopic examination show normal rail. Also tensile test except low ductility in interior of head. Sections etched shows small cracks whose origin is unknown, mostly in lower part of head.

1916 — Cause of Failure of a Shot Truck Brake Shaft, Tests of Metals, Watertown Arsenal, p. 73.

The cause of fracture in a brake shaft of shot truck for 12-inch M.C. model of 1896 was found to be cold shortness due to a very decided P segregation in streaks or bands although the chemical analysis for the whole shaft showed only 0.047 S and 0.048 P.

1916 Burgess, G.K.; Merica, P.D. — Some Foreign Specifications for Railway Materials, Tech. Paper No. 61, Bureau of Standards

1916 Cushing; Feld; Wickhorst — Committee, Sub A. R. E. A. Internal Fissures in Rails, American Railway Engineering Association, 17, p. 585.

Gives types of internal fissures, an exhaustive bibliography of internal fissures up to date and results of chemical and physical properties from 100 failed rails, tested at the Altoona Laboratory.

1916 Cushing, W.C. — Some of the Causes of Rail Failures, American Railway Engineering Association, <u>17</u>, p. 605.

The article summarizes the 4330 failures for the 4 year period '09-'12 inclusive. Makes detailed survey of 603 cases. Causes frozen road beds, high C, P, S, segregation, base seams, use of scrap plate in ingot, too light bases, too quick reduction of area ingot to bloom, too much gagging, too low temperature of rolling.

1916 Hayward, H. Effect of Sulfur on Low Carbon Steel, American Institute of Mining Engineers, Bulletin 118, p. 535; Steel and Iron, Nov.

1. The effect of sulfur is such that it does not lower the tensile strength. 2. Little difference in ductility between 0.04% S and 0.087% S but ductility is lower when S reaches 0.15%. 3. The shock resisting properties of notched bars in Charpy test machine are reduced with increasing sulfur. The widest difference appears in the steels which have been quenched and reheated. Samples used, however, were very low C. from 0.17 to 0.18% P 0.006 - 0.010%, Mn. 0.55 - 0.80%.

1916 Hirst, W. Effect of Sulfur in Steel, Power 44, p. 287.

Refers to Unger's paper and says his tests are not entirely conclusive. Questions the method for adding S to mold as different in effect from S that comes from the pig iron.

1916 Newcomb, R.E. Sulfur Content in Steel, Power, 44, p.393.

Says high S steel is not so workable by tools as low S.

1916 Oberhoffer, P. Ueber neuere Aetzmittel zur Ermittlung der Verteilung des Phosphors in Eisen und Stahl. Stahl und Eisen, 36, p. 798.

A modification of Stead's reagent. Micrographs.

1916 Schmidt, M.H. High Sulfur in Steel, Iron Age, 97, p.383.

Questions the effect of S added to the ingot as Dr. Unger did.

1916 Stead, J.E. Influence of Some Elements on the Mechanical Properties of Steel, Iron Age, 98, p. 1286; Journal of Iron and Steel Institute, 2, p. 5,

With Mn, S does not produce hot shortness but is bad if Mn is absent, due to formation of sulphide with Mn, while sulphide with Fe is bad. High S. gives better impact tests. Makes the steel somewhat fibrous. "Sulfur may be regarded as a friend when used intelligently." Effect of P is comparable to that of C if P is about 0.1%. Makes rails hard to resist wear. Effect of P on diminishing elongation appears to be largely dependent on amount of Si present. P is bad in high C. steel and has about twice the effect as same amount of C. Gives steel good machining surface if P is from 0.13 to 0.20%. Mn_3P_2 has powerful influence on mechanical properties while the phosphide distributed in ground-mass is without effect.

1916 Unger, J.S. Effect of Sulfur in Rivet Steel, Power, 44, p. 144; American Boiler Manufacturing Association, Proc. 1916.

Experiments on rivet steel with sulfur content from 0.03% to 0.18%. The specimens were submitted to hot and cold bending, flattening, and upsetting tests; were pulled apart, made up into riveted joints, etc. The fact that there was six times as much sulfur in some as in others made no apparent difference in their behavior.

1916 Unger, J.S. An Investigation of the Effect Produced by Varying the Sulfur Content of Basic Open Hearth Steel, S. A. E. Trans. 11, p. 56; Scientific American Sup. 81, p. 68; Iron Age, 97, p. 146.

As a result of tests reported, he firmly believes that a steel containing less than 0.10% S is not necessarily bad and that it will show little difference in quality when compared with same steel of much lower sulfur. Fabricating tests reported.

1916	Unger, J.S.	Sulfur Contents May Be Raised, Automobile, 34, p. 20.
1917	Carpenter, H.C.H.	Influence of Phosphorus and Sulphur on the Mechanical Properties of Steel, Nature, 98, p. 410. New light on the subject from experiences of war. Find German shells to have higher percentage than allowed in England. A summary of Stead's paper.
1917	D'Amico, E.	Influence of Phosphorus on Steel, Metallurgia Italiana 9, p. 142. Shows that brittleness under impact manifests itself prior to the appearance of the coarse crystallization due to a large percent P. Experiments on 0.1 and 0.23 percent P show about same structure in micrographs but impact test with Charpy pendulum on standard notched bars were 22.5 $\frac{kgm}{cm^2}$ and 3.05 $\frac{kgm}{cm^2}$ respectfully. The coarse crystallization did not appear until 0.56 percent P. Tensile test bars with 0.5 percent P show small elongation and contraction of area, rapid rise of yield point and breaking load and corresponding diminution of work of rupture.
1917	Fearnsides, W.G.	The Shortage of the Supply of Non-Phosphoric Iron Ore, Journal of Royal Society of Arts, 65, p. 743. British home supplies and reserves.
1917	Howard, J.E.	Transverse Fissures in Steel Rails, A.I.M.E. Bulletin 131, p. 1871. Insists such failures are result of fatigue. They have their origin in sound metal normal in structure, no micro defects to which origin of fracture can be attributed. Analysis shows no chemical reason why fissures occur when found. All due to heavy impact of wheel loads.

1917 Sauveur, Unger, Comstock — The Effect of Sulfur on Low Carbon Steel, A. I. M.E. Bulletin 124, p. 529.

Discussion of Hayward's paper. Various opinions. Sauveur warns against segregation. Unger believes S got its bad name in early days when the S content could be readily determined but other elements not. Comstock calls attention to low value of shock test results of specimens high in S.

1917 Taylor, D. — Segregation in Steel, Scientific American, 116, p. 157.

With relation to seamless tubing the segregation due to sulfur was disastrous. "It is quite astonishing how much harm a little sulfur can do when misplaced in steel."

1917 Wickhorst, M.H. — Appendix B. Transverse Fissure Rail 51051, American Railway Engineering Association, 18, p. 915.

Tests on this rail. Chemical tests all right. No fissures other than the large one found. Cross sections polished showed longitudinal cracks in interior of head.

1917 Wickhorst, M.H. — Some Transverse Fissures Rails on the L and N. R. R., American Railway Engineering Association, v. 18, p. 1189.

11 failed rails examined from 3 to 11 years old. Bending in a gag press, chemical analysis, tensile, and polishing of cross sections tests made. Two types of transverse fissures found, simple and coalescent. Chemical analysis pretty good although old rails were high in C and P, denoting hardness.

1918 Comstock, G.F. — A Metallographic Investigation of Transverse Fissure Rails with Special Reference to High P, Streaks, American Institute of Mining Engineers Bulletin 145, p. 1699; Engineering News Record, 82, p. 532, 1919.

Describes a copper etching fluid that shows up high P. streaks. Examined 24 failed and 12 good rails. Believes a long heat treatment will allow P. to diffuse and do away with Transverse Fissures.

1918 Editorial — Sulphur in Steel Castings, Iron Age, <u>101</u>, p. 757, and p. 918.

Notes increasing use of 0.06 percent or higher S. content castings. The endurance of such material in war service may bring out valuable information.

1918 Konstantinov, N.S. — Physico-chemical Investigation of Ternary Alloys of Iron with Phosphorus and Carbon, J.Russ Phys. Chem. Soc. <u>50</u>, (1) p. 311.

Electrical conductivity and hardness of binary alloys of Fe and P and ternary alloys of Fe+P+C

1918 LeChatelier, H. Bogitch, B — Heterogeneity of Steel, Academie des Sciences, Comptes Rendus etc. <u>167</u>, p. 472.

States that the macro structure developed in a steel by etching with Stead's copper reagent has been ascribed to heterogeneity in the distribution of the phosphorus. The authors find it possible to develop the same structure in steels free from phosphorus, and they suggest that oxygen remaining in solution as FeO is the real cause.

1918 McWilliam, A. — The Influence of Some Elements on the Tenacity of Basic Steel, Journal of Iron and Steel Institute, <u>98</u>, p. 43.

Results of investigations. Gives formula for tensile strength. S not an influence. P strengthens. 1000 lb. per 0.01% P.

1918 Muntz, G. — Increased Sulfur Content in Steel Castings, Foundry, <u>46</u>, p. 191.

Asks for an investigation of the effect of sulfur on steel. Points out how little is definitely known. Reviews Dr. Unger's work. Calls attention to the saving of manganese if the upper sulfur limit can be raised.

1918 Stead, J.E.

Iron, Carbon and Phosphorus, Journal of Iron and Steel Institute, 97, p. 389; Chemical and Metal. Engineering, 19, p.592.

Investigates the mutual effect of carbon and phosphorus in iron. Finds the P goes away from regions of high C. The P concentrates in solid solution in the surrounding ferrite and the concentration increases as C increases until the ferrite becomes saturated with the phosphide. The amount of carbon capable of passing into iron by cementation at any temperature less than the ternary eutectic point varies inversely with the P. Says carbon would be considered as treacherous as P if we did not know so much about carbon.

1918 Stead, J.E.

Notes on Inclusions in Steel and Ferrite Lines, Journal of Iron and Steel Institute, 97, p. 287; Engineering, 105, p. 538.

Concerns mechanically made inclusions and cavities. Ferrite or cementite does not crystallize on the walls except in case of flourspar. If P is present it is concentrated in the white ferrite lines, [illegible] When the inclusions are not associated with high P. no ferrite envelopes appear. "When P is associated with the inclusions in steels containing between 0.16 and 0.6% C ferrite lines invariably appear."

1918 Unger, J.S.
1919

Effect of Phosphorus in Soft Acid and Basic Open Hearth Steels, Proc. Steel Trade Research Society 2, p. 11, 1919; Iron Trade Review, 62, p. 149, 1918; Iron Age, 101, p. 1538, 1918; American Iron and Steel Institute Yearbook, p. 172.

None of the steels used in experiments showed brittleness under cold working, due to phosphorus. Results of various mechanical tests, cold bending of rivets under hammer, upsetting in making barrels, automobile parts and cream separators, large headed nails or rivets, or fabrication of bowls indicated increase of hardness with increase of phosphorus.

1918
1919 Committee A-1. Discussion on Specifications for Structural Steel, Journal American Society for Testing Materials, 18, p. 136; Journal American Society for Testing Materials, 19, 1919.

About adding note for raising war limits of S. and P.

1919 Fremont, C. The Premature Rupture of Steel Under Repeated Stresses, Comptes Rendus, 168, p. 54.

Fremont asserts fatigue never ruptures a piece if the elastic limit is not exceeded. Segregation and inclusion cause of early deterioration. Ordinary alternate stress and fatigue machines, and their theory take no account of the dynamic forces called into existence but are based entirely on static considerations, which is wrong.

1919 Howard, J.E. Discussion Comstock "Metallographic Investigation of Transverse Fissure Rails with Reference to High P, American Institute of Mining Engineers, Bulletin 147, p. 598.

Still insists wheel loads too high. Reviews use of different kinds of rails that for a time, are all right but heavier service puts them out of commission. Refers to the P streaks as "still obscure and the correlation of which with transverse fissures has not yet been established."

1919 Kreuzpointner, P. Limiting of Transverse Rail Fissures, Iron Age, 104, p. 530.

Formation of such fissures can be overcome by diffusion of metalloids especially P. Heat treatment will do it but such mass treatment seems impossible.

1919
1920 Matthewman, F.A. Sulfur in the Acid Open-Hearth Process, Jour. West Scotland, Iron and Steel Institute, 27, p.34.

Absorption of S. from gaseous atmosphere of furnace. Suggests coating scrap with clay wash or SiO_2 point. Discusses results obtained with coated scrap.

1919	Stomeyer, C.E.	Discussion Dr. Hatfield's "Mechanical Properties of Steel," Journal of Institute of Mechanical Engineers, p. 483.
		Says there is a sharp dividing line between reliable and unreliable steel. Good steel does not exceed 0.08% = P+5N.
1919	White, A.E.	Plea for Less Rigid Sulfur Limits, Foundry, 47, p. 691.
		Asks for a thorough survey of the items which affect the quality of steel castings and to judge their acceptability on the basis of the properties they possess rather than to lay undue emphasis on one or more disputed points. No data given.
1920	Brearley, H.	Impurities in Steel, Engineering, 130, p. 375, Journal Iron and Steel Institute, 103, p.461 1921.
		Reasons for and against retention of low S and P limits in B.E.S.A. specifications for railway materials. Tests fail to distinguish material with .03% S and P from those with .05%. .07% P has been known to give as good results as .03.
1920	Comstock, G.F.	Sulfur Segregation, Iron Age, 105, p.1784.
		Use of Al, Si and ferro-carbon-titanium as deoxidizers discussed.
1920	Hibbard, H.D.	Reversion of Phosphorus to Basic Steel in One Ladle, Blast Furnace and Steel Plant, 8, p.642.
		Cause of reversion of P is presence of reducing elements Si, Mn and C and slag SiO_2 from acid lining of ladle. Quantity of P to revert depends on amount of P in charge, amount of erosion of acid ladle lining, % reducing elements in finished steel, quantity of slag retained in ladle, consistency of slag, length of time metal is held after tapping.

1920 Oberhoffer, P. — "Slatey" Fracture and Evidence of Segregation Stahl u. Eisen, 40, p. 705,869.

Causes of segregation are discussed using diagrams and the Fe-C and Fe-P diagrams. The slatey fracture was shown to be due to segregation of P. Three forms of segregation distinguished, crystalline, ingot and blow-hole. Latter seems to be principal cause of slatey fracture.

1920 Rawdon, H.S. — Contemporary Foreign Opinion on Sulfur and Phosphorus in Steels, Chem. Met. Eng. 22, p. 609-11.

General opinion regarding method for obtaining suitable S and P contents in experimental heats appeared to be that additions should be made during heat and not at close. No clear expression of opinion as to possible detrimental effect of some obscure conditions accompanying high percentages of S and P.

1920 Smith, M.C. — Alumirum Additions and Sulfur Segregation, Iron Age, 105, p. 1426.

Tests made on steel containing 0.15% C after adding varying amounts of Al. Best results obtained from ingot to which 10 oz. Al had been added. The ladle test showed 0.046% S.

1920 Vie, G. — The Desulfurization and Dephosphorization of Iron and Steel by Slags, L'Age de Fer 36, p. 189.

Oxidizability of P. Case of S, concluded that Mn, Si and C diminish solubility of S in Fe; Mn and S form composition very slightly soluble in Fe and very soluble in basic slags; alkalies, alkaline earths and basic slags, especially in presence of C, show considerable dissolving power for S with increase of temperature. Discussed manufacture of pig iron in blast furnace to give metal containing less than 0.03% S.

1920 White, A.E. — Effect of Sulfur on Steel Castings, Iron Age, 105, p. 478.

The tendency of S to increase blow-holes, increase shrinkage and decrease resistance to shock in steel castings is relatively slight compared to other factors which may cause these same changes.

1920 Whiteley, J.H. — The Distribution of Phosphorus in Steel Between the Points Ac_1 and Ac_3. Iron and Steel Institute, 101, p. 359.

Discusses diffusion of P out of gamma iron, structure possibly due to diffusion but probably due to substance other than P.

1921 Blanchi, E. — Sulfur in Siderurgy, Giorn. Chim, Ind. Applicata, 4, p. 254.

Bases contained in slags do not constitute a desulfurizing agent that is practical and of sufficient activity. Only reagent suitable is oxygen during oxidizing period of refining, and Mn, especially during reducing period.

1921 Grigorovitch, K.P. — Desulfurization of Steel in the Martin Furnace and in the Electric Furnace, Messager de la Direction Generale del'Ind. des Metaux Russe No. 2, 1; Rev. Met. 19, p. 276, 1922.

1921 Jung, A. — Dephosphorizing of Ilseder pig-iron in the Converter and Open Hearth Furnace. Stahl u. Eisen, 41, p. 687.

Experiments with dephosphorizing Ilseder pig iron with about 3% P in an open hearth furnace. Better dephosphorization obtained in the basic converter.

1921 Oberhoffer, P.; Knipping, A. — Investigations on the Baumann Sulfur Test and a Contribution to the Relations of Phosphorus and Iron, Stahl u. Eisen, 41, p. 253.

P does not interfere with the sulfur print. Concluded pure Fe-P alloys become homogeneous by heating to 1200°. The presence of C and other alloying elements make the homogenizing more difficult.

1921 Veach, C.W. Reactions in the Basic Open-Hearth, Foundry, 49, p. 380.

Procedure of heating described. Actions of C, P, Si and Mn are shown and thermal values are given.

1921 Webster, W.R. Physics of Steel, Blast Furnace and Steel Plant p. 555, 9.

General discussion and the applications in rolling of the effects of C, P. and Mn on the mechanical properties of steel.

1921 Whiteley, J.H. Cupric Etching Effects Produced by Phosphorus and Oxygen in Iron, Iron and Steel Institute, 103, p. 277

Differences in P content of less than .02% in adjacent parts of otherwise pure Fe can be readily discovered by cupric reagents. As difference is increased, at any rate up to 0.15% the contrast becomes more pronounced.

1922 Anon Sulphur and Manganese in Rivet Steel, Chem. Met. Eng., 12, p. 1011.

Discussion of A. S. T. M. work on rivet steel.

1922 Burgess, G.K. Effect of Sulfur on Rivet Steel, American Society for Testing Material, 22, (1), p.94.

Preliminary report of Bureau of Standards investigation.

1922 Fry, A. Diffusion der Begleitelelemente des Technischen Eisens in Festen Eisen, Forschungsarbeiten zur Metallkunde .

Discusses diffusion of elements. Elementary diffusion of S and P in solid Fe takes place. Fe_3P and FeS can exist in solid iron.

1922 Goodals, S.L. Control of Silicon in the Blast Furnace Blast Furnace and Steel Plant, 10, p.3[illegible].

Influence of S taken up in connection with Si.

1922 Oberhoffer, P. Jungbluth, H. Recrystallization of Technical Iron, Stahl u. Eisen, 42, p. 1513.

Effect of P studied.

1922 Priestley, W.J., et al. Effect of Sulfur and Oxides in Ordnance Steel (disc), Trans. Am. Inst. Min. & Met. Eng., 67, p. 331.

Mentions effect of shape of ingot molds and influence on transverse and longitudinal tensile tests of S and of forging in both directions.

1922 Priestly, W.J. Effect of Sulfur and Oxides in Ordnance Steel. Trans. Am. Inst. Min. & Met. Eng., 67, p.317, Iron Age, 108, p. 1658, 1921.

Comparison of electric and open-hearth practice given. Electric steel is more uniform, more homogeneous and dense than open-hearth steel, if cast at too high a temperature, or chilled beyond a certain point in the mold incipient cracks will develop.

1922 Summersbach, B. The Question of Desulfurization of Iron and Steel, Chem. Ztg. 46, p. 65.

S derived from ore and fuel partly eliminated if Fe is held in fluid state in mixes. Suspended sulfides removed as slag. Only Thomas (basic bessemer) process causes any reduction in S. 0.177 and .092 reduced to .059 and .040% S respectively. Other processes showed a gain of S rather than a loss. S is more injurious to Fe or steel when Cu or As are present.

1922 Thum, E.E. — Effect of Sulfur on Rivet Steel, Chem. Met. Eng. 26, p. 1019.

S up to .10 in rivet steel does not affect hot or cold shortness. Each additional .01S up to .10 decreases tensile strength 200 lbs. per sq. in. and increases yield point 100 lbs. per sq. in. Quenching accentuates effect of S. S has strong effect on impact strength but practically no effect on hardness. Maximum S now allowed in structural steel rivets (.045%S) is at least .01% below the point where S will damage the strength of a well made rivet steel, as far as its performance can be predicted by known tests.

1922 Webster, W.R. — Application in Rolling of Effects of Carbon, Phosphorus and Manganese on Mechanical Properties of Steel, Trans. Am. Inst. Mining, & Met. Engrs. 67, p. 220.

Gives extensive tables of the effect of variations of C content and P content on the tensile strengths of steels.

1923 Bauer, O. — The Segregation of Phosphorus in Ingot Steel, Mitt. Materialprufungsamt, 40, p. 71.

A discussion of the injurious effect resulting from the segregation of P in steel.

1923 Burgess, G.K. — Effect of "Added" Sulfur on Structural Forging and Rail Steels, Am. Soc. Test. Materials, 23 (1), p. 105.

Data are presented for tests on 236 samples of steels to which S has been added in the later stages of manufacture. Data for a Bureau of Standars technologic paper.

1923 Campbell, E.D., Ross, J.F., Fink, W.L. — The Relative Efficiency of Dry and of Moist Hydrogen on the Decarburization of Steel at 950° and the Effect of Hydrogen on the Phosphorus Content, Jour. Iron and Steel Institute, 108, p. 179.

Neither moist nor dry H at 950° has any effect upon the P content of the steel.

1923 Fry, A. — Diffusion of Accompanying Elements of Technical Iron in Pure Iron, Stahl u. Eisen, 43, p. 1039.

Ferro-phosphorus, iron-sulfide and electrolytic iron used. Highest concentration of P was 1.17, S indistinguishable under microscope. With more than 1 element present P is more easily diffused, also S. When both are present one aids in diffusion of other.

1923 Schreiber, K.A. — Influence of Phosphorus on the Microstructure of Iron, Metallborse, 13, p. 2240.

Below 0.1% there was no apparent influence on microstructure. With 0.5% P a definite P-containing eutectic is recognizable. With P of 3% or more phosphoric constituent showed tendency to crystallize with striated structure and suppress other constituents, especially ferrite. At same time the Fe showed so-called flaky structure.

1923 Williams, S.V. — Control of Sulfur in the Basic Open-Hearth Steel Process, Blast Furnace and Steel Plant, 11, p. 51.

Sources of S in open-hearth steel considered and means for limiting the amount stated. Method of preventing absorption of S from fuel and of removing it from molten bath reviewed. Saniter process, clay coating of scrap, effect of Mn discussed.

1923 Wust, F. — The Influence of Some Foreign Substance on the Shrinkage or Iron, Giesserei Zeit, 10, p.191, 203.

Effect of P and S. Approximate 1.7 P gave minimum shrinkage of 1.3, above which content the shrinkage again increased. Relation between shrinkage values and phase diagram. Up to 1% S shrinkage decreased rapidly; less rapid decrease above 1%S.

1924 Anon

Effect of Sulphur and Alternating Stress on Steel, Engineering News, Record, 93, p.172.

Abstracts of A. S. T. M. papers.

1924 Anon

Manganese and Phosphorus in Iron and Bronze, Canadian Foundryman, 15, p. 18

Traces hardness of iron to S. P weakens iron more than any other element in commercial cast iron. Increases fluidity, counteracts tendancy of S to increase combined C, shrinkage, contraction and chill. .2-.7%P in iron not subjected to high temperatures assists in production of good castings.

1924 Bogitch, M.B.

Sulfuration et Desulfuration des Metaux par les Scories ou Laitiers Basiques. Rev. de Met. 21, p. 682.

Discusses desulphurization by calcium fluoride in molten state; in solid state by heating with C.

1924 Burgess, G.K. et.al.

Effect of Sulfur on Endurance Properties of Rivet Steel, Am. Soc. Test. Matls., 24, (1), p. 96.

Average C .115, Mn .442, S .0282-.1793, P .0055-.0240. Tables and curves show endurance properties of material subjected to two types of heat treatment. Determination of endurance limit by "accelerated fatigue" method is more reliable than determination of limit of proportionality in the stress-deflection graph.

1924 Burgess, G.K. et al.

Effect of Sulfur on Structural Steel, Am. Soc. Test. Matl., 24, (1), p. 185.

S from .03-.08, C .19-.25, Mn .41-.48, P .012-.015, Si .007-.028. Tension, impact, hardness bending and shear tests given both in natural condition "as received" and in annealed condition. Curves show variation of physical properties with varying S content in natural, annealed normalized and quenched conditions. Average C and Mn content plotted against average S content of each heat.

1924 Burgess, G.K. et al — Metallographic Investigation of Effect of Sulfur on Rivet Steel, Am. Soc. Test. Mat's. 24, (1), p. 108.

Macroscopic examination, non metallic inclusions and microscopic examination discussed. S prints. As S increases inclusions other than sulfides decrease. Any direct effect of S on physical properties of steel is probably due to effect of manganese sulfide inclusions but their effect is obscured by the effect of other inclusions particularly in low S steel. As S increases there is a general variation from coarse network to finer network and then to granular structure. With higher S the granular structure predominates.

1924 Cain, J. R. — Influence of Sulfur, Oxygen, Copper and Manganese on the Red-Shortness of Iron, Bureau of Standards Tech. Paper 203.

If S is below .01 there is no red-shortness even when the O content is 0.2%. If S is above .01 a Mn:S ratio of 3.0 is sufficient to prevent red-shortness.

1924 Feild, A.L. — Effect of Zirconium on Hot-Rolling Properties of High Sulfur Steels and the Occurrence of Zirconium Sulfide. Trans. Am. Inst. Mining Met. Engrs., 70, p. 201; Chem. Abstract, 18, p. 2317.

Hot rolling properties of high S steels described Zr. reacts with S to form ZrS_2. Zr completes deoxidizing before combining with S and indirectly increases effective S-combining power of any Mn which may be present.

1924 Ishiwara, T. — The Effect of Impurities on the Dendritic Structure in Carbon Steels and Their Diffusion at High Temperatures, Sci. Report, Tohoku Imperial University, 12, p. 309.

0.1% P shows pronounced dendritic structure, S less effective than P. Minimum concentrations of Mn, Si and P which make ingots dendritic are nearly equal to amounts of these elements actually present in ordinary steel. P retards diffusion of C. P makes steel electronegative to cupric reagent, S positive.

1924 Kinney, C.L. Economic Significance of Metalloids in Basic Pig in Basic Open-Hearth Practice, Trans. Am. Inst. Min. & Met. Eng., 70, p. 136; Blast Furnace and Steel Plant, 12, p. 45; Iron Age, 113, p. 718, 755.

Effect emphasized of varying percentage of P in basic pig iron on cost of steel. Data sheets worked out.

1924 Maurer, E., Haufe, W. Influence on the Hardening of Tool Steels of Elements Usually Considered Detrimental, Stahl u. Eisen, 44, p. 1720.

Effect of S and P on tool steel containing 1.2% C investigated. S appeared to act only indirectly by formation of sulfide inclusions. A steel with 1.2% C and 0.462% extraneous elements (S,P,As, Cu,Sn) was slightly less sensitive to hardening than one with 0.97% and only 0.134% of the same elements. Fractures of quenched specimens unfavorably affected by P and Sn.

1924 Palmer, R.H. Sulfur as a Hardening Agent, Foundry 52, p.894.

Advantage shown of a small S content (about 0.1%) in chill castings particularly where a special charge is not justified. The S is added to the ladle.

1925 Anon Effects of Sulfur, Phosphorus, Carbon, Manganese and Silicon in Steel, Auto, Ind. 52, p. 267.

S causes tendency to red-shortness; P to cold-shortness. Both should be kept down to .05.

1925 Drysdale, G.A. Desulphurization of Ferrous Metals, American Foundrymen's Association, 33, p. 557.

Discussed desulphurization by use of limestone, borax, slag, sodium-carbonate. Gives sulphur contents of metal desulphurized in the ladle and in the cupola by sodium carbonate.

1925 Faust, E. Production of Different Types of Steel in the Thomas Converter, Stahl u. Eisen, 45, p. 1739, 1701.

Suitable conditions for production of high P steel discussed. S content for pig-iron and telegraph wire discussed. In production of steel of high P content (.28-.40) in the basic converter the Mn in the pig-iron should not exceed 1.3%.

1925 Greaves, R.H., Jones, J.C. Temper-Brittleness of Steel; Susceptibility to Temper-Brittleness in Relation to Chemical composition, Jour. Iron and Steel Institute, 111, p. 231.

P increases susceptibility to brittleness. Tables are given and curves show the relation between susceptibility and P content.

1925 McIntosh, F.I., Cookrell, W.L. The Effect of Phosphorus on the Resistance of Low-Carbon Steel to Repeated Alternating Stresses. Carnegie Inst. Min. & Met. Inves. Bull. 25.

Fatigue tests on plain and notched specimens of low C steels (less than 0.15C) with P from .010 to .125%. Addition of this amount of P to such steels increases endurance against repeated alternating stresses, increases hardness, ultimate strength and elastic limit, has no bad effect on resistance to shock or vibrating stress, increases resistance to corrosion and abrasion, has no well defined effect on ductility.

1925 Piwowarsky, E. Phosphide in Manganese Steel, Stahl u. Eisen, 45, p. 1075.

1.39 C, 14.2 Mn, 0.13 P. P eutectic in grain boundaries. Suggests that solution of phosphide eutectic increases the contraction of the iron.

1925 Robinson, S.R. Carbon Steel and Carbon Vanadium Steel by the Converter Process, American Foundrymen's Association, 33, p. 655.

S removed by treatment in the ladle with alkali compound; kept below .05%. P kept below .05% at all times.

1925 Von Eckermann, H. A Method for Reducing the Percentage of Phosphorus in Swedish Iron by Diminishing the Phosphorus in the Charcoal, Jour. Iron and Steel Institute, 111, p. 379.

Discusses cutting of wood for charcoal and floating to carbonizing plant to reduce P.

1926 Burgess, G.K. et al Effect of Phosphorus and Sulfur in Steel, Am. Soc. Test. Matls. 26, (1) p. 114.

Showed no systematic relation between any of physical properties determined and S content up to .06%. With S content above approximately .06% the values of certain properties decreases with increase of S content.

1926 Anon Effect of Sulphur on Rivet Steel, Engineering News Record, 97, p. 26.

Abstract of Am. Soc. Test. Matls. work.

1926 Report of American Foundrymen's Association, representative on Joint Committee on Investigation of Effect of Phosphorus and Sulfur in Steel, American Foundrymen's Association, 34.

1926 Anon Sulphur in Steel, Metallurgist, Jan. 29, p. 10.

Discusses Levy's work on the influence of Mn on the condition of S in iron. Work of Rohl on FeS-MnS system discussed. Results of Arnold's work on effect of S in iron and steel in absence of Mn quoted.

1926 Andrew, J.H., Dickie, H.A. Physical Investigation Into the Cause of Temper Brittleness, Journal Iron and Steel Institute, 114, p. 359.

Tendancy for special elements (P) to increase solubility of carbide in ferrite at temperatures near Ac_1 range and redeposit it from solutions at lower temperatures on slow cooling.

1926 Angiolani, A. Steel Manufacture. The Theory of the Elimination of Phosphorus, Sulfur and Oxygen. Industria (Milano) 40, p. 116.

Quality of steel may be injured by more than .06-.08 P or .05 S. Various methods used in steel industry from viewpoint of thermodynamics and mass-action equations. Slags considered. Extensive mathematical discussion.

1926 Blackall, A.C. Effect of Phosphorus on Swedish Iron Ores, Blast Furnace and Steel Plant, 14, p. 22.

Abstract of article by Eckermann on reduction of P by treatment of coke.

1926 Dickenson, J.H.S. A Note on the Distribution of Silicates in Steel Ingots, Iron and Steel Institute, 113, p. 177.

Percentage of slaggy matter in form of small globular silicate particles rose to a maximum in the central lower part where C, S, and P were each reduced to a minimum by segregation. Applied equally to C, Ni and Ni-Cr steels, to top cast and bottom cast ingots.

1926 Esser, H., Oberhoffer, P. The Binary System Silicon-Iron; Iron-Phosphorus; iron-manganese. Ber. No. 69, Werkstoff-schusses des Vereins Deutscher Eisenhuttenleute; Bhysik. Ber. 7, 106.

With the increase of P content the temperature of A_3 transformation increases. Below 2.4% Si (0.4% P) at temperatures of 1100 the alpha-gamma change can no longer be observed. The temperature of the gamma-delta change decreases with increase of P.

1926 Keats, J.L., Herty, C.H. Chemical Equilibrium of Manganese, Carbon and Phosphorus in the Basic Open-Hearth Process, Am. Inst. Min. Met. Engr., 78, p.1107.

Amount of P in metal is determined by total P in charge, the iron oxide content of slag, its basicity, volume and temperature. Relation between these variables is expressed quantitatively and amounts of P calculated agree with amounts found by experiment.

1926 Kjerrman, B. The Effect of Manganese, Silicon and Phosphorus on the Pearlite Interval, Am. Soc. Steel Treat. 9, p. 430.

Ac_1 point occurs over a range of temperatures instead of at a definite temperature in steel containing Mn, Si or P. Previous heat treatment does not affect the range caused by Si of P.

1926 McIntosh, F.F. Effect of Phosphorus on the Endurance Limit of Low-Carbon Steels, Min. & Met. 7, p. 332.

Tests on basic open-hearth steel containing 0.10% C and P .01-.10 showed increasing strength, hardness and ability to withstand fatigue in direct proportion to P content. Impact tests equally satisfactory. P considered an alloying element capable of conveying valuable properties to steels.

1926 Read, T.T. General Principles in the Benefication of Iron Ores, Blast Furnace and Steel Plant, 14, p.294.

Effects of P in steel and premiums and penalties for it in ores are discussed. Also effects of S and means of eliminating S in the blast furnace and open-hearth and examples of treatment of S-bearing ore.

1926 Rolfe, R.T. The Effect of Phosphorus in Steel, Min. & Met., 7, p. 518.

The author is not in agreement with some of the statements made by McIntosh (J. Iron and Steel Inst., 1926, p.631) and points out the deleterious effect of high P in steels from a structural standpoint.

1926 Tubojatzky, E. Scientific Principles in the Production of Definite Types of Steel, Monysn Tanfdvhsu 18, 321,353,382.

Laws of mass action and reaction rate applied to removal of P and S. Slag formation considered, use of Mn, deoxidation.

1926 Whiteley, J.H. On Ghost Lines and the Banded Structure of Rolled and Forged Mild Steels, Jour. Iron and Steel Inst. 113, p. 213.

Only when variations of % of P between two adjacent areas in iron exceed 0.08% do they cause removal of C between Ar_3 and Ar_1 from the richer area. In some cases C may move from one region to another of higher P concentration.

1927 Anon Auf Frage der Entschwefelung Von Eisen. Zeit. f. die Gesamte Giessereipraxis 48, p. 386.

Describes work of Drysdale on use of Na_2CO_3 or KOH mixture for desulphurizing.

1927 Anon The Effect of Phosphorus in Steel, Min. & Met. 7, p. 518; Mechanical Engineering, 49, p. 163.

Regards P as a prejudicial impurity to be kept down to as low a proportion as possible. Discusses effect of P in relation to free-cutting steel.

1927 Burgess, G.K. et al Progress Report of the Joint Committee on Investigation of the Effect of Phosphorus and Sulfur in Steel, Am. Soc. Test. Matls., 27 (1), p. 131.

1927 Burgess, G.K. et al Effect of Sulfur on Plate Material: Conclusions, Am. Soc. Test. Matls., 27, (1), p.135.

S content varying from 0.03 to .08%. Concludes S up to .077 is not detrimental, tests showing no systematic relation between any of the physical properties determined and the sulfur up to .077%.

1927 Cameron, A.E. — Phosphorus and Arsenic in Steel and the Substitution Theory, Canadian Min. Met. Bull., 177, p. 88; Am. Soc. Steel Treat, 11, p.486.

Relative effect of As and P in steel upon physical properties. Bibliography.

1927 Hibbard, H.D. — Parallel Between Sulphur and Oxygen in Steel Metallurgy, Fuels and Furnaces, 4, p.1445.

Effect of O and S on red-shortness, weldability, removal by Mn, use in making rimmed steel.

1927 Roll, F. — Die Diffusion im Metallischen Zustand, Insbesondere die des Schwefels und Phosphors im Gusseisen, die Giesserei 14, p. 1; Foundry Trade Journal, 35, p. 83.

With H_2S (heated 350-400°), S penetrated 2 mm. in 24 hours. Percentage 40.65 in outer layer to 20.5 in inner. Micrographs of effect of diffusion of S on structure. Phosphide eutectic also showed great capacity for diffusion

1927 Bull, R.A. — Report of American Foundrymen's Association Representative on Joint Committee on the Investigation of the Effects of Phosphorus and Sulphur in Steel, American Foundrymen's Association, 35, p. 230.

EFFECT OF SULPHUR AND PHOSPHORUS ON CAST IRON

1871 Bell, I.L. On Some of the Conditions Which Apparently Affect the Quality of the Iron, Journal Iron and Steel Institute, 2, p. 288.

Infers the "richness" of iron is, within limits, entirely independent of its chemical composition. But it is generally thought that an excess of sulfur hardens iron.

1871 Bell, I.L. On the Behavior of Phosphorus and Sulfur in the Blast Furnace, Journal Iron and Steel Institute, 2, p. 277.

The undoubted evil produced by the presence of phosphorus or sulfur in iron confers an interest upon any fact connected with their action in a blast furnace.

1875 Pearse, J.B. Iron and Carbon, Mechanically and Chemically Considered, Trans. Am. Inst. Min. Engrs., 4, p. 157.

Gives tensile test results and chemical analyses of cast iron guns. P decreases the tenacity.

1878 Bell, I.L. Separation of Phosphorus from Pig Iron, Jour. Iron and Steel Institute, p. 17.

Gives details of separation of C and P from iron by heating and remelting with basic oxides.

1878 Holley, A.L. The Strength of Wrought Iron as Affected by Its Composition and by Its Reduction in Rolling, Trans. Am. Inst. Min. Engrs., 6, p. 101.

Results of numerous tests with chemical composition. P 0.20% with C about 0.03% and Si under 0.15% gave the best chains.

1878 Howson, R. The Art of Puddling, Journal Iron and Steel Institute, p. 575.

Discusses quality of pig iron best adapted for puddling to remove the P. This is easiest removed from pig low in Si.

1878-9 Drown, T.M. Experiments on the Removal of Carbon, Silicon and Phosphorus from Pig Iron by Alkaline Carbonates, Trans. Am. Inst. Min. Engrs., 7, p. 146.

Details of an experiment in which carbon and silicon and phosphorus were removed from cast iron during an alkaline fusion.

1879 Coxe, W.E. Note on the Wear of an Iron Rail, Am. Inst. Min. Engrs. 8, p. 62.

An iron rail made at Reading in 1870 in heavy traffic for 9 years. Content P 0.422%, S 0.032%, C 0.027%.

1880 Hudson, W.J. Behavior of Sulfur in the Manufacture of Iron, Journal Iron and Steel Institute, 1, p.213.

The effect of S on castings was to cause frequent fracturing while the iron was in a half solid condition.

1885 Platz, B. The Chemical Changes which Occur on Heating and Tempering Cast Iron, Journal Iron and Steel Institute, II, p. 643.

The author by various tables and chemical analyses shows how on heating, phosphorus and silicon tend to liquate. The article gives the percentage of Si and P to be found in the scale in several tables.

1886 Schneider, I. Occurrence of Phosphorus in Pig Iron, Journal Iron and Steel Institute, II, p. 913.

Various chemical analyses of pig iron are given in proof that phosphorus is present as iron phosphide and manganese phosphide. It would appear that the affinity existing between phosphorus and manganese is greater than that between phosphorus and iron and that this is the reason for improvement in phosphoric pig by the addition of manganese.

1887 Cheever, B.W. Two Conditions of Phosphorus in Iron, Trans. Am. Inst. Mining Engrs., 16, p. 269.

Concludes phosphorus exists in iron in at least two conditions, as phosphide and as phosphate and that the phosphide is the injurious condition; the phosphate being present in the form of slag. The iron should be so produced as to have as much as possible of its phosphorus oxidized to phosphoric acid.

1888 Turner, T. Silicon and Sulfur in Cast Iron, Journal Iron and Steel Institute, p. 28.

On the mutual interaction of silicon and sulfur. It appears probable that with a certain percentage of silicon there is a definite amount of sulfur which cannot be exceeded under given furnace conditions. In a blast furnace, a low temperature favors the union of sulfur and iron, the composition of the slag influences the sulfur content.

1889-1890 Keep, W. J. Phosphorus in Cast Iron, Am. Inst. Min. Met. Engrs., 18, p. 458.

An account of the influence of phosphorus on the grain of cast iron, also on the chill, strength and other physical properties.

1889 Ledebur, A. Weak Spots in Ingot Iron Test Pieces, Stahl u. Eisen, 9, p. 13.

Finds failure often occurs where segregation is present. Here S may be 0.30% while in the sound portion it is but 0.04%.

1890 Ledebur, A. The Effect of Phosphorus on Iron, Stahl u. Eisen, 10, p. 513.

Comments on different effects of P on weld iron and on ingot iron, 0.40% P in weld iron may not make it cold short while 0.20% P will make ingot iron distinctly cold short. He believes low P content makes for toughness in steel.

1890 Ledebur, A. — Physical Properties of Cast Iron, Journal Iron and Steel Institute, II, p. 828; Stahl u. Eisen 10, p. 602.

P lowers the melting point of cast iron and also diminishes the tendency for the formation of blow-holes. It diminishes the tensile strength and does not increase the hardness greatly. Modulus of elasticity diminishes with increased load.

1892 Ball, Wingham — Experiments on the Elimination of Sulphur from Iron, Journal Iron and Steel Institute, 1, p.102

Two methods for removal of S from cast iron. Addition of strong alkali together with a cyanide or ferrocyanide; alkali is reduced and combines with the S. Addition of rich ferro-manganese; preferential combination of Mn and S which can be skimmed off as slag.

1893 Hilgenstock, G. — Elimination of Sulphur from Iron, Journal Iron and Steel Institute, 44, p. 435; Stahl u. Eisen, 13, p. 451,823.

Disagrees with J. E. Stead on manner in which lime combines with S in the desulfurization process. Gives chemical formula for reaction.

1894 Arnole, J.O. — The Physical Influence of Elements on Iron, Journal Iron and Steel Institute, 45, p.107.

An investigation of the influence of the elements on the recalescent points showing that the influence is not governed by any periodic law.

1894 Drown, T.M. — Segregation in Iron, Journal Iron and Steel Institute, 45, p. 591.

On solidification the impurities are always concentrated in the last part of the freeze. C, P and S are elements most liable to segregation.

1894	Keep, W.J.	Sulfur in Cast Iron, Am. Inst. Min. & Met. Engrs., <u>23</u>, p. 382. Effect of sulfur on the physical properties of cast iron together with various notes tending to destroy the feeling that S is very objectionable in cast iron.
1894	Ledebur, A.	Sulphur in Iron, Journal Iron and Steel Inst., <u>46</u>, p. 477; Stahl u. Eisen, <u>14</u>, p. 336. Lime is not capable of decomposing ferrous sulfide without a reducing agent.
1895	Editorial	Ingot Iron, London Engineering, <u>80</u>, p. 330. Weakness generally traceable to a greater percentage of impurities than should be allowed. P content should be especially watched.
1895	West, T.D.	Diffusion and Segregation of Metalloids at the Furnace and Foundry, Industries and Iron, <u>19</u>, p. 502. Methods of lessening their evil effects. Variations in composition is ably discussed.
1895	West, T.D.	Segregation and Means to Lessen the Effect, Iron Age, <u>56</u>, p. 1210. Examples of concentration of metalloids in different parts of the crucible. Relate mainly to S and Si, but P and C are also discussed.
1896	McDowell, M.	Practical Value of the Various Metalloids in Cast Iron, Iron Age, <u>58</u>, p. 161. Results of researches and experiments, followed by discussion. Estimates one part of S neutralizes 10 of Si. A little P makes better castings.
1896	Roberts-Austen	On the Rate of Diffusion of Carbon in Iron, Iron and Steel Trades Journal. In relation to the question of the passage of S and sulphides into the center of the ingot, especially the passage of solid C into solid Fe.

1896 West, T. D. Effects of Expansion on the Shrinkage and Contraction of Iron Castings, Trans. Am. Inst. Min. Engrs., 26, p.165.

Tests show S is harmful in cast iron. Up to 0.30% S can easily be present in iron containing 1.5% Si, 0.20% S being enough to injure or ruin almost any casting.

1897 Knight, S.S. Sulfur in Iron, Foundry, Jan.

Some remarks on the harmful results of too large quantities of sulfur.

1897 Von Juptner Der Einfluss des Phosphors auf Kalt-bruch, Stahl u. Eisen, 17, p. 524.

A valuable paper giving analyses and tests and discussing the various forms in which P appears in combination.

1898 Bachman, F.E. Silicon and Carbon in Cast Iron, Am. Inst. Min. Engrs., 28, p. 769.

138 grades of foundry iron. Inspection of the tables seems to show a close relation between sulfur contents and carbon.

1898 Johnson, G.R. On the Action of Metalloids on Cast Iron, Industries and Iron, 25, p. 208; Journal Iron and Steel Inst., 54, p. 200.

Discussed the effect of each element on the properties of the iron and on the state of the other metalloids with tables of tensile tests in which each element in turn is varied, the others being held constant. Ultimate tensile strength increased as S increased, but decreased when P increased.

1898 Summers, B. Modern Cupola Practice with Special Reference to the Discussion of the Physics of Cast Iron, Am. Inst. Min. Met. Engrs., 28, p. 396, 884.

Tables giving the influence of oxidizing material. Data concerning the effect of Si, C, P, etc. on the properties of cast iron.

1899 Moldenke, R. Cast Iron, Railroad Gazette, 31, p. 171

Considers chemical properties, the making of tests, etc.

1900 Howe, H. M. Influence of Silicon and Sulfur on the Condition of Carbon in Cast Iron, Am. Inst. Min. Met. Eng., 30, p. 719.

Silicon precipitates graphite and adds that S raises the saturation point of the solidifying iron in respect to carbon.

1900 Howe, H. M. Influence of Silicon and Sulfur on Carbon in Pig Iron, Trans. Am. Inst. Min. Met. Eng., 30, p. 719.

Tends to support work previously done by Turner, Saniter, Keep and others.

1900 Johnson, J.E. The Chemistry and Physics of Cast Iron, Briefly Considered, Am. Mach., 23, p. 316.

Furnishes information from the large experience of the author.

1900 Kreuzpointner, Discussion, The Chemistry and Physics of Cast Iron, Jour. Frank. Inst., 150, p.329, 460.

Discussion of a paper entitled "Riddles wrought in iron and steel."

1900 Stead, J.E. Iron and Phosphorus, Jour. Iron and Steel Inst., 58, p. 60.

Iron phosphide present both as a eutectic with ferrite and also as solid solution and therefore in homogeneous distribution. Appendix and bibliography are attached.

1901 Bolling, R. Irregular Distribution of Sulfur in Pig Iron, Jour. Am. Chem. Soc. 23, p. 798.

Concludes that to obtain a true sample of sulfur iron for a sulfur determination, the bar should be drilled through from top to bottom and the drillings thoroughly mixed.

1901 Carnot, A., [illegible]tal, [illegible] — Notes on the Chemical Composition of Cast Iron and Steel, Metallographist 4, p. 286.

From "Annales des Mines". An account of investigations dealing with the elements. Chemical.

1901 Henning — Foundry Iron, Journal American Foundrymen's Association, 9, p. 121.

Showing that chemical and physical investigations are of value to the foundry industry and equally necessary at the blast furnace.

1901 Howe, H.M. — The Constitution of Cast Iron, with Remarks on Current Opinion Concerning It, Trans. Am. Inst. Min, Engs., 31, p. 318; Metallographist 6, p. 303, 1903.

An attempt to select the most probable working hypotheses, in studying the relation between the chemical compositions and physical properties.

1901 Stead, J.E. — Iron and Phosphorus, Metallographist, 4, p.89, 199, 332.

Gives all details of effect of P on iron from all different view points.

1901 West, T.D. — Characteristics of the Chemical and Physical Properties of Cast Iron, Siberian Journal of Engineering.

Shows the utility of chemical analyses and discusses the effects of treatment and composition.

1902 Dillner, G. — Pig Iron for Castings, Bihang Till Jernkontorets Annaler, p. 363; Oesterreichische Zeit, f. Berg und Huttenwesen, 1, p.670.

Discusses effects of impurities, as S on physical properties of cast iron, S makes iron white and hard and causes it to absorb gases which are thrown out on solidification and cause blow-holes.

1902 Keep, W.J. — Cast Iron, A Record of Original Research, J. Wiley and Sons, p. 82.

Depth of chill is uninfluenced by S. No indications of evil results from the highest S in the series. S is, however, in no way beneficial.

1902 LeChatelier, Ziegler — Sulfure de fer, Bull. de la Soc. d'Encourag; Metallographist 6, p. 19, 1903.

A study of the state in which sulphide of iron exists in cast iron, and the nature of its influence on the metal.

1902 Longmuir, P. — Cast Iron, Journal American Foundryman's Association, 11, p. 61.

Reviews the constituent elements and their effect on the quality and the purpose to which the iron is adapted.

1902 Scott, W.G. — Effect of Variations in the Constituents of Cast Iron, Foundry, Sept.; Am. Soc. Test. Matls., 2, p. 181.

Describing the influence of metalloids on cast iron as observed under practical conditions without reference to theory.

1903 Wust, F. Schuller — Sulfur in Iron, Stahl u. Eisen, 23, p. 1128.

Amount of S contained in cast iron is dependent on the amount of Si present.

1903 Johnson, J.E. — The Chemistry and Physics of Cast Iron in the Light of Recent Knowledge, American Machinist, 26.

A review of the advance made during the last three years, mentioning some important articles dealing with this subject.

1903 Wust, F. — Manganese Ore as Desulphurizing in the Cupola, Stahl u. Eisen, 23 (2), p. 1134.

By addition of manganese ore in cupola practice S was reduced from .111 to .0[illegible]

1904 Campbell, H.H. Quelques Experiences sur la Diffusion des Sulfures a Travers l'acier, Rev. de Met. 1, p. [illegible].

1904 Field, H.E. Defects in Cast Iron, Iron Trade Review, p. 5[illegible].

Effect of S and P on shrinkage, blowholes, cold shuts and weakness generally.

1904 Johnson, J.E. Notes and Observations on Cast Iron, Am. Inst. Min. & Met. Eng., 35, p. 212.

Current practice in removing Si and S from cast iron given, together with means of controlling carbon.

1904 Webster, W.R. Note on the Further Discussion of the Physics of Cast Iron, Trans. Am. Inst. Min. Engs. 35, p. 147.

A list of the contributions to the transactions bearing on this subject since 1895.

1905 Messerschmitt, A. Sulphur Distribution in Castings, Stahl u. Eisen, 25, p. 895.

S rises in a casting as the metal solidifies but the way it does so is dependent on other conditions, such as the thickness of metal in the casting, rate of solidification, or height of casting. Variations in mechanical properties due to irregular distribution of S. discussed.

1905 Stead, J.E. Sulfures et Silicates de Manganese dans l'acier, Rev. de Met., 2, p. 337.

1905 Ward, G.J., Longden, A.H. Effect of Sulphur on Siliceous Pig Iron, Jour. Soc. Chem. 24, p. 186.

Glazing on siliceous pig iron not due to S but to iron silicide.

1906 Adamson, E. Influence of Si, P, Mn and Al on chill in cast iron, Journal Iron and Steel Inst., 69, p. 75.

Describes experiments made to determine the influence of these metalloids on chill, and to obtain comparative data on mechani-

cal tests and other conditions. P has some influence in reducing the percentage of combined carbon, and decreases the strength in transverse and deflection tests.

1906 Fettweis, F. Phosphides and Carbides of Iron, Metallurgie, 3, p. 60.

Redetermination of P content gave composition of 15.8% P which correspond to formula Fe_3O.

1906 Hiorns, A. H. Effects of Elements in Structure of Cast Iron, Journal Soc. Chem. Ind., 25, p. 50.

Series of samples with increasing P and a sample with 1 percent of S are described. In the latter, sulfide of iron could be observed and no graphite.

1906 Houghton, L. Some Notes on the Chemistry of Cast Iron, Iron Trades Review, 39, p. 4.

Considers C, Si, Mn, S and P.

1906 Moldenke, R. Cupola Practice, Iron Age, 77, p. 516.

Removal of S discussed.

1906 Richarme, M.E. Theory and Practice of Dephosphorizing of Cast Iron, Wrought Iron and Steel, Bull. Ind. Min. 5, p. 183.

Exhaustive treatise on theory and practice of dephosphorization, heat reactions and basic slags, limits and choice of materials. Practical applications.

1906 Stead, J.E. Crystallization and Segregation of Steel Ingots, Iron and Coal Trades Review, 73, p. 1595.

Summary of the results of about 30 years as given by J.E. Stead in two addresses on above subject and conclusions from his own investigations.

1906 Stoughton, B. Foundry Mixture, Iron Trade Review, p. 25.

Discussion of influence of foundry mixtures on shrinkage and porosity of castings, softness, workability and strength. Effect of presence of Mn and S in causing a casting to check is also briefly investigated.

1906 Stoughton, B. Foundry Mixtures, Iron Age, 78, p. 1302.

P keeping iron fluid longer gives more time for free carbon to separate out.

1906 Wust, F. Uber die Abhangigkeit der Graphitausscheidung von der Anwesenheit Fremder Elemente in Roheisen, Metallurgie 3, p. 200.

The solubility of C in Fe is lessened by S but S does not promote its conversion to temper C; on the contrary, it neutralized the action of Si in this respect.

1907 Hailstone, G. Action of Metalloids on and the Microstructure of Foundry Irons, Proc. S. Staffordshire Iron and Steel Inst.

S makes iron more fusible and liquid by formation of fluid sulfides; tends to form combined C, the iron is harder and possesses greater shrinkage; causes blow holes, with high temperature of castings; deep chill, segregation and blow hole formation encouraged.

1907 Henderson, J. Note on the Distribution of Sulfur in Metal Ingot Moulds, Journal Iron and Steel Inst., 23, (1), p. 286.

Finds the sulfur much higher in the top inch from such molds. Recommends taking chemical analysis samples from the bottom.

1907 Houghton, E. Ferro-Alloys in the Foundry, Electrochem. Met. Ind. 5, p. 512.

Ferromanganese and spiegel are added to remove S. Manganese is added to eliminate S. Ferro phosphorus is used to make cast iron more fluid and for use in fine and intricate castings.

1907	Howe, H.M.	Maniere dont le Carbone et le Phosphore se Comportent dans l'acier, Rev. de Met. 4, p. [illegible].
1908	Gutowsky, N.	Technical Cast Iron Containing Phosphorus, Metallurgie, 5, p. 463.

At 980 the parts containing P begin to melt and may float off, consequently use of such mixtures at high temperatures is out of the question.

1908	Levy, D.M.	Iron,Carbon and Sulfur. Metallurgie, 5,p.32?.

Addition of S to cast iron has tendency toward formation of white iron. S-free melts were gray, those containing up to .08% S were mottled, while those richer in sulfur showed a white crystalline fracture. When less than .9% S was present it was distributed uniformly, but with more present the S concentration was greater in the upper part of the metal.

1908	Osann, B.	Calculation of Cupola Dimensions with Relation to the Question of Hot Blast and Temperature of the Hearth, Stahl u. Eisen 28, p.1449.

The S content of pig iron remains the same in remelting with normal coke charges. Desulfurization due to liberation of SO_2 produced by reduction of Fe and Mn alloys high in S.

1908	Wust, F.	Influence of Phosphorus on the Fe-C system. Metallurgie 5, p. 73.

Deals with the decrease produced by P on the solubility of C in Fe. Work of previous investigators is reviewed.

1909	Adamson, E.	Pig Irons and Their Use, Iron and Coal Trade Review, 78, p. 302.

Classifies the various pig irons and briefly considers the effect of C,Si,S, P and Mn. S is not such a deadly enemy as it is often made out to be. P retards the rate of cooling at the recalesence points and also lowers the strength of cast iron in transverse test.

1909 Goerens, P. Effect of Foreign Substances on the Fusion Diagram of Fe-C Alloys, Metallurgie, 6, p.537.

Investigation of two systems Fe-Mn-C and Fe-P-C. When Fe is added to the alloy the substance only becomes modified and not fundamentally altered.

1909 Hiorns, A.H. Influence of Chemical Compounds on the Properties of Cast Iron, Chem. Eng., 10, p.98; Mechanical Engineering, 21, p. 170.

Effect of P and S is considered in respect to blow-holes, chill castings, segregation and shrinkage.

1909 Orthey, M. Der Einfluss der Fremdkorper auf die Festigkeitseigenschaften des Gusseisens, Giesserei Zeit, 6, p 12, 45, 75, 161.

Discusses the effects of the various impurities commonly found.

1909 Stead, J.E. Alloys of Iron, Carbon and Phosphorus, Jour. Soc. Chem. Ind. 28, p. 712.

1910 Eakins, E.E. The Chemistry of Cast Iron, Iron Age, 85, p. 1146; Iron Trade Review, 46, p. 1030

Discusses heat treatment and the influence of chemical compounds upon the casting. P has no effect on the contraction of cast iron except mechanically in enlarging the eutectic mixture. The effect of S depends on the amount of Mn present. In the absence of Mn, S in Fe promotes contraction during cooling.

1910 Liesching, T. The Influence of Sulfur Upon the System Iron-Carbon, Metallurgie, 7, p. 565.

Micrographs show that S when present in sufficient amounts appears in the eutectic in 2 forms; as lines between grains, which form appears in alloys up to 1% C, and as small globules. Eutectic contains 31% S. Bibliography given.

1910 Stead, J.E. Effect of Sulfur and Silicon on the Carbon Condition of Cast Iron, Engineering, 90, p. 508.

Experiments with high-S & low-S irons with Mn, S crystallized as MnS previous to solidification of carbide, the metal then turning gray on cooling. Not more than .001 part S is taken up by Fe, and it is this S which prevents the separation of C as graphite.

1910 Stead, J.E. The Effect of Sulfur and Silicon on Cast Iron, Nature 84, p. 302.

Discusses the effect of these substances on the carbon content of commercial cast iron from the metallurgical point of view.

1910 Wust, F., Felser, H.L. Der Einfluss der Seigerung auf die Festigkeit des Fluss Eisen, Stahl u. Eisen, 30, p. 2154.

In general less phosphorus segregation takes place in a large ingot than in a small one. Sulfur on the other hand segregates to a greater extent in the larger ingots and in those which cool slowly.

1911 Carpenter, H.C.H. The Growth of Cast Irons After Repeated Heatings, Iron and Coal Trades Review, 82, p. 751.

Considers the effect of S, P and Mn and gives report of experiments to find a commercial alloy whose growth is negligible. Phosphide iron grows relatively slowly while S has no appreciable effect.

1911 Carpenter, H.C.H. Permanent Enlargement of Cast Iron After Repeated Heating, Journal Iron and Steel Institute, 83, p. 196.

P, S and Mn help to retard the growth.

1911 Levy, D.M. Manganese Sulfides and Silicates in Iron and Steel, Journal Iron and Steel Institute, Carnegie Schol. Memoirs, 3, p. 260.

1911 Pardun, C. — Uber das Verhalten des Schwelfel beim Kupolofen-Schmelzen, Stahl u. Eisen, 31, p.665.

A large amount of sulfur in the coke of the furnace passes over to the iron [illegible]ed. It is nearly impossible to prevent this except that manganese may aid.

1911 Porter, J.J. — Influence of Various Elements on the [illegible] of Cast Iron, Trans. American Foundrymen's Association, 19, p. 35; Iron Age, 88, p.1077; Iron Trade Review, 49, p. 839.

The chief factors which influence fluidity are the S and P percentages, absence of dissolved oxide, and heighth of temperature above melting point. The factors influencing the capacity of castings to resist high temperature are the P and S percentages (0.03% S and 0.70% P) and combined carbon in addition to closeness of grain.

1911 Porter, J.J. — The Physical Properties of Cast Iron, Iron Age, 88, p. 1077.

Gives facts showing their independence of the chemical composition of pig iron and their relation to methods of blast furnace operation. Sulfur, if not oxy-sulphide form, may not be bad for cast iron.

1912 Coe, H.I. — The Influence of Sulfur on Cast Iron, Mechanical Engineering, 30, p. 219.

Briefly considers the reasons for the presence of S in cast iron, its effect on the physical and mechanical properties, the elimination, etc. Resume of Stead's and Levy's work.

1912 d'Amico, E. — Uber den Einfluss des Phosphors auf die Eigenschaften des Flusseisens, Ferrum, 10, p. 289.

The increase of 0.10% P up to 0.41% affected the quality to the degree as follows: the elastic limit is raised 2.32 tons. The ultimate tensile strength is raised 4.1 tons. The elongation is reduced 1.36%. The contraction of area is reduced 3.81%. Brinell hardness number is increased 12 points.

1912 Hatfield, W.H. The Constitution of Cast Iron, Foundry, 40, p. 326.

Dealing with the constituents of cast iron, and some of the changes produced with heat treatment.

1912 Turner, T. The Solidification of Iron Castings, Met. Chem. Eng., 10, p. 160.

Ordinary phosphoric gray irons expanded 3 times, all three expansions occurring after the bar had become solid from ordinary point of view.

1912 Venator, W. Uber die Physikalischen und Chemischen Eigenschaften des Gusseisens, Giesserei Zeit, 9, p. 282.

Review and discussion of J.J.Porter's paper.

1912-1913 Lissner, A. Formation of Temper Carbon in Cupola Furnace Tempered Castings, Ferrum, 10, p. 44.

White cast iron with varying quantities of S and FeSi. With .4% Si and .15% S, the decomposition of the carbide starts at 765°, with 1.24% S at 1020°C.

1913 Carnevali, F. Cast Irons Containing Phosphorus, Turin. Rass. Min. 39, p. 21.

Castings made of gray iron containing P which is commonly used for such purposes are much harder and more brittle when they are reheated at 1000° than those reheated at 800°. Gives physical properties of three groups of different compositions. Microstructure discussed.

1913 Coe, H.I. The Influence of the Metalloids on the Properties of Cast Iron, Journal Iron and Steel Institute, 87, p. 361.

S increases the strength in a remarkable manner. There is no evidence that high S content results in the formation of blow holes. P affects the chilling action of the sand on irons low in Si. 0.1% P appears to strengthen cast iron but 0.2% results in a hard, weak, brittle material.

1913 Greene, A.I. — Electric Heating and the Removal of Phosphorus from Iron, Am. Inst. Min. Engrs, Bull. F

Explains the metallurgical reactions by which P can be removed from iron.

1913 Hatfield, W.H. — Influence of Sulfur on the Stability of Iron Carbide in the Presence of Silicon, Engineering, 95, p. 683.

Fact that S increases stability of Fe_3C at high temperatures probably a chemical effect rather than a mechanical one as suggested by Levy, Study of "balling up" theory; contradicted. Probably the small amount of S associated with the carbide accomplishes the action.

1913 Heike, W. — The Desulfurizing of Iron, Its Laws and Their Application, Stahl u. Eisen, 33, p. 765, 811.

Two steps in desulfurization; liquidating of MnS and FeS; dissolving of sulfides by slag.

1913 Johnannsen, O., Heike, W. — The Desulfurizing of Iron, Its Laws and Application, Stahl u. Eisen, 33, p. 1403.

Discussion of paper by W. Heike.

1913 Schebanow, W. — Die Bekampfung des Mangan-Sulfids und die Lunkerbildung, Journal der Russ. Met. Ges. p. 508.

Rapid cooling of solid steel prevents a diffusion of manganese sulfide segregation. A considerable pipe is therefore unavoidable so that this procedure is to be used only with alloy steels.

1914 Blackwood, F.F. — Iron and Its Properties, American Foundrymen's Association, 23, p. 358.

Deals with the principal properties of cast iron and its behavior when alloyed with certain other elements. He also discusses the influence of S, P. Mn and Al, and Cu on Fe. The red shortness caused by S is due to the absence of a sufficient amount of Mn to form MnS which reduces the melting point, hence FeS is present in the metal. P produces

brittleness under shock. It is also a cause of segregation and therefore of porosity. Has found P exerts no influence on the C in steel.

1914 Coe, H.J. — The Influence of Phosphorus on Cast Iron, Stafford-Shire Iron and Steel Inst., 29.

1914 Heike, W. — The Influence of Phosphorus on Cast Iron, Stahl u. Eisen, 34, p. 918.

Increasing the P from 0.1% to 1.0% exerts the same influence as about 0.25% Si, the tensile and transverse strength increasing with increasing P up to 0.3%. P decreases somewhat the quantity of combined C and depth of hardening. Small quantities of P seem to favor the separation of graphite while larger quantities prevent it.

1914 Higgins, D.J. — Broken Main Depletes Waltham's (Mass) Water Supply, Engineering Record, 69, p. 332.

Broken pipe brittle due to high Si and P.

1914 Johnson — The Influence of Quality of Cast Iron Exerted by O, N, and some other elements. Am. Inst. Min. Engrs., Bull., 85, p. 1; Trans. Am. Inst. Min. Engrs., 35, p. 212.

Presents facts with proofs that seem to establish them. P up to 0.50% or more exercises a beneficial influence on the strength of the iron and the depth and character of the chill. It also has the tendency to reduce total carbon.

1914 Rosenhain, W. — The Distribution of Phosphorus in Cast Iron, Met. and Chem. Engineering, 12, p. 650.

Describes method of etching to show the presence of phosphorus in cast iron.

1914 Stead, J.E. — Some of the Ternary Alloys of Iron, Carbon and Phosphorus, Journal Soc. Chem. Ind., 33, p. 173.

Discusses structures in high phosphorus irons. Ghost lines in large forgings have their origin in segregation of P. A bibliography is appended.

1914- Wust, F. Stotz, R. — Uber den Einfluss des Phosphor die Mechanischen Eigenschaften des Graven Gusseisens, Ferrum, 12, p. 89.
1915

Investigation of the influence of phosphorus on gray cast iron. Test bars with various percentage of phosphorus were prepared. The transverse test gave a mean breaking strength from 39.60 Kgm per sq. mm for 0.16% P down to 25.80 with 2.04% P. The hardness at the same time increased from 234 (Brinell) to 327.

1915 Carr, W.M. — Controlling the Sulfur in Melting Pig Iron, Foundry, 43, p. 189.

S cannot be kept low nor reduced in the cupola; it can be in the open hearth. For low-S iron, the metal should be melted in a cupola and run into an open hearth for the elimination of S by adding FeMn.

1915 Leber, E. — Sulphur in Cast Iron, Stahl u. Eisen, 35, p.877.

Tables from several authors are given showing strength of cast iron with increasing S content.

1915 Slocum, C.V. — Old and New Methods of Making Car Wheels, Iron Age, 96, p. 676.

High S is allowed in Fe car wheels although such practice is dangerous.

1915 Stead, J.E. — Iron, Carbon and Phosphorus, Engineering, 99, p. 569, 611, 637.

Contains a review of all recent work and a bibliography of 58 subjects together with a note explanatory of the behavior of P in Fe.

1915 Vollenbruck, O. — Desulfurization in Cupola Practice, Iron Age, 96, p. 463.

Summarizes the results obtained in desulphurization by absorption by CaO and various Mn and Ca silicates; by varying wind pressure, by smelting with C; by the effect of the oxidizing flame.

1915 G.B.W. Effect of Sulfur in Cast Iron, Iron Age, 9_, p. 1551.

Quotes from Professor E. Legur's article in Stahl u. Eisen, Jungst in "Contributions to the investigation of cast iron" and Coe in the Journal of Iron and Steel Institute, to show the effect of S depends upon presence of C and Si. Data.

1916 Evans, G.S. Introducing Phosphorus Into Cast Iron, Foundry, 44, p. 315.

P may be introduced in cast iron to affect its fluidity but doubts whether it is commercially feasible.

1916 Hatfield, W.H. Phosphorus in Iron and Steel, Journal Iron and Steel Institute, 92, p. 122; Journal Chem.Soc. 110, II, p. 142.

The presence of .20 P or less in white irons containing about 2.9% C has but little effect upon the properties of the metal. When 0.25% P is present, free phosphide can be detected by means of Stead's copper reagent.

1916 Hurst, J.E. The "growth" of internal-combustion engine cylinders, Engineering, 102, p. 97.

Reduction of P content eliminates radiating cracks, which are not due to "growth"; due to repeated solution and precipitation of free C which is assisted by P content and liquation of P eutectic.

1916 Johnson, J.E. The Chemical and Physical Properties of Foundry Irons, Met. Chem. Engineering, 15, p. 530,588,642,683.

Classification of irons, Fe-C diagram, nature and effects produced by C and the effects of Si, S, P, O, Mn,Ni, Cr, Ti and V are described in detail.

1916 Porter, J.J. Chemical Standards for Cast Iron, Foundry, 36, p. 251; Castings 6, p. 158.

The replacing power of Si, P, Mn, etc. for C and the effect of these and of Ni, Li, V, Al, etc, are discussed. Figures show best chemical composition for castings for all purposes.

1916 Stadeler, A. Zur Metallurgie des Gusseisens, Stahl u. Eisen, 31, p. 933, 1034

Reviews the work of Ledebur, Keep, Wust and others on the influence of the various elements on cast iron.

1917 Mauland, T. High Sulfur in Soft Gray Iron, Met. Chem. Eng. 17, p. 383.

1917 Ramp, P.R. Some Unusual Results of Cast Iron Tests, Iron Age, 99, p. 1187.

S makes Fe hard in general.

1917 Wust, F., Miny, J. Uber den Einfluss des Schwefels auf die Mechanischen Eigenschaften des Grauen Gusseisens, Ferrum, 14, p. 113.

The action of sulfur is dependent upon the manganese content but not on the silicon content. High sulfur castings show no more proneness to porosity than do low sulfur castings. Hardness rises with increasing sulfur.

1918 Knostantinov, N. S. Physico-Chemical Investigations of Ternary Alloys of Iron with Phosphorus and Carbon, Journal Russ. Phys. Chem. Soc. 50, I, p.311.

Electrical conductivity and hardness of binary alloys of Fe + P, and ternary alloys Fe + P + C. Microstructure is discussed.

1918 Mauland, T. High Sulfur is Not so Bad as it is Painted, Foundry, 46, p. 84.

The possibility of producing excellent steel with as much as 0.50% S and soft iron castings with nearly 0.2% S is shown.

1918 Mauland, T. Influence of Sulfur in Soft Grey Iron, Trans, Am. Foundrymen's Association, 26, p. 552.

S considered detrimental though castings up to 0.12% will sometimes be good, strong and soft. At other times castings are hard with less than 0.09%. Hence S is not determining factor in hardness. His results seem to show S is not as detrimental as it is usually represented to be.

1920 Elliott, G.K. Electric Furnace and the Sulfur Problem in Cast Iron, Iron Age, 106, p. 919.

Duplex process of producing low-S cast iron. S more than .05 shows tendency to segregate. Advantage of low-S is reduction to a minimum of non-metallic intercrystalline film. Indirect advantage of low S is that it gives independence of high Mn and reduction of machine shop costs.

1921 Bronn, T. The Synthetic Preparation of Foundry Pig and Its Properties, Stahl u. Eisen, 41, p. 881.

By the addition of a P-rich iron high in C to a basic steel a synthetic foundry iron can be prepared which is equal in properties of Swedish charcoal iron.

1921 Daeves, K. The Computation of the Eutectic Points and the Limits of Solution in Systems Containing Iron, Zeit, Anorg. Allgem. Chem. 115, p.290.

Binary systems of P with Fe, eutectics, discussed.

1921 Guertler, W. Improvement of Cast Iron by Addition of New Elements, Giesserei Ztg., 8, p. 134.

Only two groups of elements are practicable because of cost or physical properties: Sn, Sb, S, P and As; Mn, Cr, Mo, Si, Al, Ni, W. V. In no case is the brittleness reduced or the ductility increased since the carbide and graphite are not eliminated. The addition of any element may thus far be said to be of

small value and it is suggested that combinations of foreign elements be tried to improve the properties of cast iron.

1921 Connection Between Shrinkage and Mixing of Cast Iron, Giesserei Ztg., 8, p. 135.

P decreases tendency to pipe.

1922 Apfelbock, M. The Use of Flourspar in Iron Castings, Giesserei Ztg., 9, p. 265.

Without the use of flourspar it was not possible to cast uninterruptedly with addition of 55% scrap on account of continuous increase of S content. By use of flourspar the use of scrap could be increased 5-10%, 20% Fe with 0.12% S could be added without S of final cast Fe exceeding 0.10-0.11% or any defects appearing.

1922 Bolton, J.W. Influence of Graphite on Iron, Foundry, 50, p. 436.

Sulphides occur in graphite flakes, S may occur in Fe as SO.

1922 Bolton, J.W. Phosphorus Formations in Iron, Foundry, 50, p. 787.

Microscopic study of the P structure in cast iron. Proofs to show existence of a series of P-rich alloys rather than the eutectic form in gray iron. Etching methods outlined.

1922 Cook, F.J. American Versus British Gray Cast Iron, Iron Age, 109, p. 1659.

S is not regarded as very dangerous.

1922 Graziani, G. Influence of Temperature Upon the Mechanical Properties, Giorn, Chem. Ind. Applicata, 4, p. 53.

A higher content of P is more likely to give good values for tensile resistance at high temperatures.

1922 Masing — Desulfurization of Cast Iron by the Walther Process, Naturwissenschaften 10, p.167.

Process consists of stirring into molten Fe a desulfurizing agent made up of alkali and alkali earth compounds. 40-70% S is thus removed. Desulfurization more complete the higher the temperature (up to 1450°) and longer the time (7015 min.). Reagents added are removed as slag.

1922 Scharlibbe, L. — Desulfurization of Molten Cast Iron, Giesserei Ztg., 19, p. 43; Journal Soc. Chem. Ind., 41, p. 296A

Walter process. 60% of S removed; metal also freed from gases. Difficult to remove slag due to its fluidity.

1922 Walter, R. — Desulfurizing Metals, British Patent 179,146.

Alkaline earths, etc. for desulphurizing formed into lumps before adding to metal bath.

1922 Walter, R. — Increase of Sulfur in the Cupola, Giesserei Ztg. 19; Cleveland Tech. Inst. 1, p. 29.

Iron containing about 0.15% S will take up little or no more S in the cupola.

1922 Williams, C.E., Sims, C.E. — A Study of Carburization in the Manufacture of Synthetic Cast Iron, Trans. Am. Electrochem. Soc. 41; Foundry, 50, p. 390.

Neither Si nor P have any effect on rate or degree of carburization. S probably decreases rate and degree.

1922 Wust, F., Bardenheuer, P. — High-Grade Low-Carbon Cast Iron (Semi-Steel), Mitt. K. W. Inst. Eisenforschung 4, p. 125; Giesserei Ztg. 10, p. 320.

Review with tabulated data on the influence of C, Si, Mn, P and S on the strength of cast iron. Fine state of division of graphite in purest form of pearlite attained with low C and S and high Mn.

1923 Bauer, O. — A Contribution to the Study of the Dependence of Shrinkage and Piping in Cast Iron on the Ore Mixture, Stahl u. Eisen, 43, p. 1239.

White irons always gave greater piping and shrinkage than gray irons regardless of the effect of other elements or of temperature. Si and P favor graphite precipitation and decreased shrinkage; Mn and S inhibited graphite precipitation and increased shrinkage. Best results with high Si and P and low pouring temperatures.

1923 Bauer, O., Sipo, K. — Experiments to Explain the Dependence of Shrinkage and the Formation of Pipes in Cast Iron on the Composition of the Mixture, Giesserei Ztg., 10, p. 459.

With increasing P total shrinkage decreased steadily. Influence of S slight, a very small increase in shrinkage occurring with increasing S. Increasing P decreased piping. Increasing S increased piping at first, then decreased and then increased again. S favors both shrinkage and pipe formation.

1923 Bock, J.E. — Chemistry in Semi-Steel, Iron Age, 112, p.397.

Duties of foundry chemist. Some facts about effect of C, Mn, S, P and Si are stated.

1923 Moldenke, R. — Desulphurization of Cast Iron, Foundry Trade Journal, 27, p. 203.

1923 Schreiber, K.A. — Influence of Phosphorus on the Microstructure of Iron, Metallborse, 13, p. 2240.

Below 0.1% P there was no apparent influence on microstructure. With 0.5% P a definite P-containing eutectic was recognizable. Discusses structure of 1 and 3% P irons.

1923 Smith, A.E.M. Notes Relative to Gray Cast Iron, Foundry Trade Journal, 27, p. 346; Cleveland Tech. Inst., 2, p. 413.

Influence given of C,P,S,Mn,Ti and Al on mechanical properties.

1923 Wust, F. The Influence of Some Foreign Substances on the Shrinkage of Iron, Giesserei Zeit, 10, p. 191.

Influence on shrinkage of pure Fe of C, Si, Mn, P, S, Ni, Cr in alloys. Approximately 1.7% P gave minimum shrinkage of 1.3% above which shrinkage again increased. Up to 1% S the shrinkage decreased rapidly; less rapid decrease above 1% S.

1923 Wust, F. Influence of Various Substances on the Shrinkage of Iron, Stahl u. Eisen, 43, p. 713.

Effect of P,S,Mn,Ni and Co on Shrinkage studied and tabulated.

1924 Fletcher, J.E. Sulfur in Coke and Cast Iron and the Methods Proposed for Its Elimination or Neutralization. British Cast Iron Res. Assoc. No.6, p.4.

A resume of work on this subject.

1924 Hamusumi, M. The Distribution of Graphite in Cast Iron and the Influence of Other Elements on Its Strength, Sci. Report Tohoku Imperial University, 13, p. 133.

P stiffens the Fe up to 0.3%. Further addition should be avoided in machine castings. 1-3% P favors decomposition of cementite. Above 3% it increases combined C. S strengthens Fe up to 0.1% and is not detrimental up to this amount.

1924 Hurst, J.E. The Influence of Phosphorus on Cast Iron, Foundry Trade Journal, 30, p. 433; Iron and Steel Inst. 111, p. 550.

Influence and mode of occurrence of phosphorus in cast iron is summarized from the work of Stead, Wust and others.

1924 Hurst, J.E. The Influence of Sulphur in Cast Iron, Foundry Trade Journal 30, p. 377; 35, 1927, p. 314,419; Iron and Steel Inst. 111, p. 550.

Work of previous investigators on condition and influence of S in cast iron summarized. S in presence of sufficient Mn exists almost wholly as MnS; in this form is practically without influence on structure and properties of cast iron. In absence of Mn, forms iron sulfide which tends to prevent formation of graphite.

1924 Jaederstrom, I. The Influence of Various Elements on the Shrinkage of Cast Iron and Steel, Testing, 1, p. 290.

Effect of P and S on shrinkage. Shrinkage and cooling, and expansion and shrinkage curves given.

1924 Rogers, F. The Phosphorus Eutectic in Cast Iron, Nature, 114, p. 275.

Photomicrograph to show phosphide eutectic in gray cast iron at 5000 diameters.

1925 Anon Desulphurising Cast Iron with Soda Ash, Foundry Trade Journal, 31, p. 174.

No evidence to indicate physical properties of cast iron are improved by lowering S content. Use of soda ash conserves Mn. Tables of compositions of iron treated with soda ash, and tensile strength of treated and untreated irons are given.

1925 Anon Soda Ash, and Sulphur in Cast Iron, Foundry Trade Journal, 31, p. 173.

Results of Griffing Wheel Co.'s work with soda ash described. Good S reduction obtained, Mn conserved; no improvement in tensile strength.

1925 Castle, G.C. — De-Sulphurization, Expulsion of Gases and Refining of Cast Iron, Foundry Trade Journal, 31, p. 248.

Discusses advantages of de-sulphurising by reduced cost of charge, reduced loss of castings, speeding up of machining, reduced waste of iron, use of cast iron scrap, increased price obtainable for desulphurised cast iron.

1925 Fletcher, J.E. — Relation of Ferrous Metals, Foundry 53, p.878, 890,929.

S content rises rapidly in proportion to the number of times the metal is remelted and to the amount of scrap in the mixture. Maximum S content is reached more rapidly as % of scrap in cupola charges increases.

1925 Larsen, H. — Low Phosphorus Cast Iron for Automobile Cylinders, Giesserei Ztg. 22, p. 450.

The requisite fluidity of iron with low P content can be obtained by sufficient heating. Gives casting practice of Daimler Motor Co.

1925 MacKenzie, J.T. — The Influence of Phosphorus on the Total Carbon Content of Cast Iron, American Foundrymen's Association, 33, p. 445; Iron and Steel Inst., 112, p. 470.

Gives curves showing the effect of phosphorus on the carbon content. A lengthy discussion with tables and curves by J. W. Bolton is appended.

1925 Mehrtens, J. — Desulphurization, Degasification and Deoxidation Processes, for High-Grade Cast Iron, Stahl u. Eisen, 45, p. 449.

Influence of limestone, flourspar and increased Mn contents as desulphurizor described. Describes methods of desulphurizing by degasification and deoxidation. Tables of mechanical properties of cast iron before and after desulphurizing.

1925 Partridge, J.E. The Magnetic and Electrical Properties of Cast Iron, Journal Iron and Steel Inst., 112.

P has little effect. S increases specific resistance.

1925 Piwowarsky, E. Refining Cast Iron by Alloy Additions, Stahl u. Eisen, 45, p. 289.

Swedish iron with 3.01% total C used as base. S and P to amounts found in technical irons had a favorable effect on properties of the base material, and in their presence Ni and Cr had a greater effect than on the pure Fe.

1925 Wagner, A. Desulfurization and Reduction in Cupola Furnaces, Stahl u. Eisen, 45, p. 1202.

Manganiferous desulfurizing media in cupola practice. S in Fe reduced 18-36% by use of ferro-manganese slag. Desulfurization more certain than when fluorspar was used.

1926 Bolton, J.W. Phosphorus Affects Qualities of Gray Cast Iron, Foundry 54, p. 378, 423.

P does not strengthen Fe but presence of phosphide network shows that cooling conditions favored high strength. In strong Fe, high P increases machinability. P increases brittleness, stiffness of Fe and promotes, but is not essential for fluidity. P advantageous when fluidity and abrasive hardness are desired and shock resistance and machinability are not necessary.

1926 Ciochina, J. Problem of Sulphur in Cast Iron and in Steels, Chimie et Ind. 15, p. 389.

S on cast iron and steel in liquid state. Disproved idea that S tends to migrate and concentrate in one place. Methods of analysis, effect of increase of Mn on S content, rise of S content in open-hearth process discussed.

1926	Denecke, W., Meierling, T.	Bemerkungen zur Entschwefelung des Gusseisens und zu Seiner Veredlung durch Rutteln, Giesserei Ztg., 23, p. 569. No noteworthy effect of shaking on sulphurization.
1926	Hurst, J.E.	The Condition and Influence of Sulphur in Cast Iron, Foundry Trade Journal, 34, p. 323,355. A review of present-day knowledge concerning the influence and mode of existence of S in cast iron as brought out by the results of different investigators.
1926	Jungbluth, H., Gummert, H.	The Correlation of Teeming and Annealing Temperatures on the Extent and Development of the Iron Phosphide Eutectic, Krupp. Monatsh, 7, p. 41. Proportion of iron-phosphide eutectic decreases as the casting temperature increases. Annealing gray cast iron at 700 and below tends to segregate the phosphide.
1926	Irresberger, C.	Agitation Improves Iron, Foundry, 54, p.773. Up to 55% of original content of S at blast furnace may be eliminated by thorough agitation of hot melt.
1926	Kennedy, R.R., Oswald, G.J.	Effects of Various Alloys on the Growth of Gray Iron Under Repeated Heatings, Met. Ind. Lond. 29, p. 395. Addition of 1% extra P to gray cast iron decreased growth greatly.
1926	Kikuta, T.	On Malleable Cast Iron and the Mechanism of Its Graphitization. Sci. Report, Tohoku Imperial University, 15, p. 115. S hinders graphitization and should be limited to below .06%. P should not be over .3%.

1926 MacKenzie, J.T. How Phosphorus Influences Cast Iron, Foundry, 54, p. 681.

P involves lower C in cast Fe. Deflection at given load increases with P content.

1926 MacKenzie, J.T. The Influence of Phosphorus on Cast Iron, American Foundrymen's Association, 34, p.986.

Analyses, bending curves, Brinell hardness, drop tests of a number of irons. P is shown to lower the strength and resilience and increase Brinell and stiffen bar slightly. In some cases P by promoting fluidity and hence soundness actually helps to make a stronger casting.

1926 Meierling, T. Denecke, W. Desulphurization of Cast Iron, Giesserei Ztg., 23, p. 175; Iron and Steel Inst., 113, p.554.

By blowing the metal very hot desulphurization takes place when the charge has somewhat cooled due to freezing out of mixed crystals rich in manganese and iron sulphides. Effect is the same whether the metal is high in sulphur or has only a normal content. If blowing is not vigorous no desulphurization takes place as the metal is too viscous for crystals to rise.

1926 Shaw, J. Influence of Elements on Cast Iron Structure, Foundry, 54, p. 767, 771, 825.

Manganese found to cause no decrease in S content of Fe in actual practice. No relation shown between gain of S and loss in Mn.

1926 Smalley, O. Investigations on Heat and Scale-Resisting Cast Irons, Foundry, 54, p. 946,994.

S and P had both good and bad effects, the bad predominating. High P or S caused brittleness at high temperature though not increasing the scaling and 0.2% of each is recommended.

1927	Anon	Affinage et Desulfuration de la fonte, Fonderie Moderne, 21, p. 56.
		Explains fou... zation. General nature.
1927	Anon	Desulfurization of Cast Iron, Bull Brit. Cast Iron Res. Assoc. No. 15, p. 24.
		Bibliography of 31 references to periodical literature and 10 references to patent literature covering the period 1920-1926.
1927	Anon	The Influence and Condition of Sulphur in Cast Iron, Iron and Steel Ind. 1, p.37.
		Considers sulphur in cast iron. Many instances where S may be objectionable, others where even high S effects may be neutralized by that of Si and still more, of Mn present. Often expense of using costly low-S iron and low-S coke is incommensurate with benefits obtained.
1927	Anon	Iron Castings and Their Production, Commonwealth Engineering, 14, p. 225.
		Effect of S and P in castings reviewed.
1927	Ciochina, J.	Sulfur Problem in Cast Iron and Steel, Chimie & Ind. 17, p. 383.
1927	Dennison, W.E.	Influence of the Phosphor Content of Cast Iron on the Resistance to Compression and Tensile Stresses, Foundry Trade Journal, 35, p. 229.
		Deterioration of gray cast iron when P content is raised from 0.8 to 1.2%. Gradual reduction of compression strength with increase of P. Tensile tests fairly constant from 0.8 to 1.0% P. when there is a slight but steady depression to 1.2%.
1927	Everest, A.B.	Nickel and Nickel-Chromium in Cast Iron, Bull. British Cast Iron Res. Assoc. 16, p.14.

Effects of nickel will depend largely on initial Si and P contents of Fe.

1927 Herty, J.H., Gaines, J.M. — Desulfurizing Action of Manganese in Iron, Am. Inst. Min. Met. Eng., 75, p. 434.

On elimination of S in the ladle, final content of S and Mn is (%Mn) (%S) =0.070, provided (%Mn) (%S) is greater than 0.07 at the furnace. The higher the Mn the lower the S after the elimination has ceased. S elimination shown to cease 1 hour after pouring.

1927 Hurst, J.E. — The Influence of Sulphur in Cast Iron, Foundry Trade Journal, 35, p. 314,419.

In presence of sufficient Mn, S is converted to MnS which is harmless up to appreciable amounts. FeS in appreciable amounts will not have any serious effect in presence of higher Si and total C contents. According to Piwowarsky exaggerated demands for removal of last traces of S in high Mn cast irons are not justified in light of modern knowledge.

1927 Kennedy, R.R. Oswald, G.J. — Phosphorus and Titanium Retard Growth of Cast Iron, Foundry, 55, p. 387; Fonderie Moderne 21, p. 415.

Explains retarding effect of P and Ti on basis of envelope of steadite around grains which slows rate of penetration of gases causing growth. Rate of growth of a deoxidized iron should be slower.

1927 Pinsl, H. — The Effect of Prolonged Annealing on the Phosphide Eutectic, Stahl u. Eisen, 47, p.537.

Phosphide eutectic, in consequence of diffusion of phosphide in patches can be completely removed on prolonged annealing (of cast iron) and phosphorus becomes highly segregated.

1927 Rolfe, R.T. Sulphur and Desulphurization in Cast Iron, Iron and Steel Ind. 1, p. 3.

The problem of S in foundry practice, the extent to which it is prejudicial, the extent to which it may be harmless and the associated problem of desulphurization and its ways and means are discussed.

EFFECT OF SULPHUR AND PHOSPHORUS ON MALLEABLE IRON.

1915 Hemenway, H. Calculating Mixtures for Malleable Cast Iron, Am. Foundrymen's Association, 23, p.413.

P in connection with Si has an influence on the fluidity of iron. There will be no bad effect if the amount of P present does not exceed 0.20%. There are no beneficial results arising from the presence of S and it should be less than 0.045%.

1915 Smith, R.H. Sulfur in Malleable Cast Iron, Journal Iron and Steel Inst., 92, p. 141; Iron Age, 96, p. 1235.

Research to ascertain if sulfur is removed by annealing and what conditions favor removal. S does not appear to have any markedly injurious effects on the product until about 0.15% is present. Higher percentages give unsatisfactory bending tests and low deflections.

1916 Touceda, E. Permissible Phosphorus Limits in Malleable Iron Castings, Am. Foundrymen's Association, 24, p. 209.

Finds P up to 0.325% content has no effect on the grain size of malleable iron. The evil effects of P are slow to make themselves felt if the combined C is low.

1918	Teng, J.H.	Phosphorus in Malleable Cast Iron, Journal Iron and Steel Inst., 98, p. 349.
		Investigations undertaken to determine the effect of proportions of phosphorus varying from 0.05 -0.5% on the mechanical properties of malleable cast iron. The addition of P does not improve the mechanical properties of malleable while above 0.20% the properties are impaired.
1919	Davis, P.H.	Effects of Phosphorus on Malleable Cast Iron, Foundry, <u>47</u>, p. 258.
		Discussion on Teng's paper and Touceda's paper on this subject.
1919	Merrick, A.W.	Sulfur Reduced in Malleable Iron, Foundry, <u>47</u>, p. 685.
		High sulfur iron refined in electric furnace. Duplex process permits Fe of any C and Si content to be made by proper additions of steel and Fe-Si. Permits increase of amount of scrap used in cupola.
1923	Oberhoffer, P., Welter, J.	Investigation of the Manufacture of Malleable Iron, Stahl u. Eisen, 43, p. 105,301.
		Behavior of S in malleable iron. Impact figures decrease with increasing S. Cupola castings on account of higher S should be annealed at higher temperatures if ductility is required. Mn practically neutralizes effect of S. With low S, S is absorbed by iron; with high S as iron sulfide, a decrease in S occurs. Distribution of S investigated by microscopic and macroscopic methods.
1927	Gilmore, L.E.	Proper Sulphur-Manganese Ratio Must be Maintained, Foundry, 55, p. 734.
		Gives details of the regulation of sulphur in malleable cast iron by the use of enough manganese to form manganese sulphide instead of iron sulphide.

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