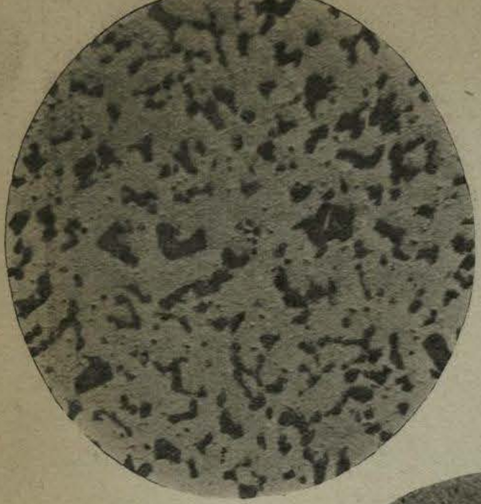
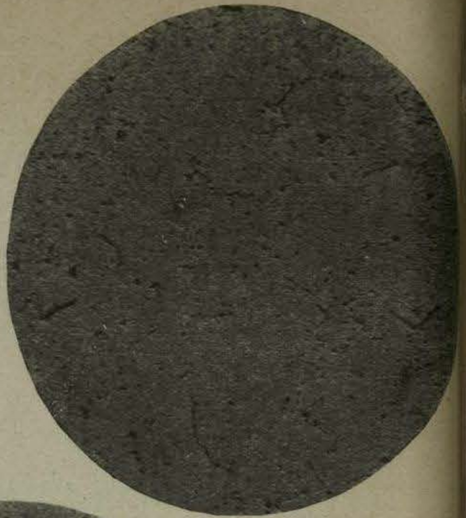
Photo-Micrographs showing Change in Microstructure induced by Heat Treatment.

STEEL No. 1.—MAGNIFICATION 100 DIAMETERS.

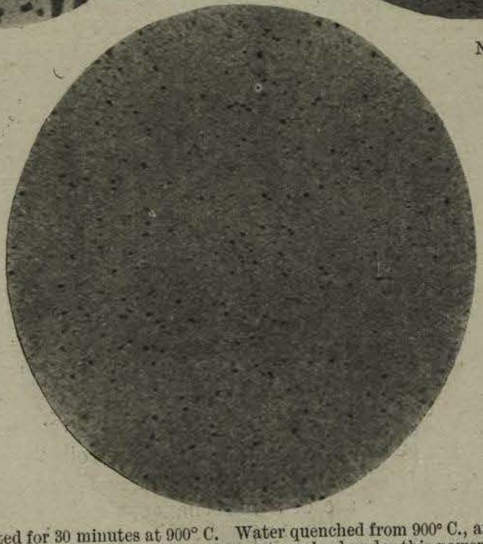
Carbon, ·16.



No. 1.—Annealed for 30 minutes at 900 C.; slowly cooled. Pearlite and Ferrite.

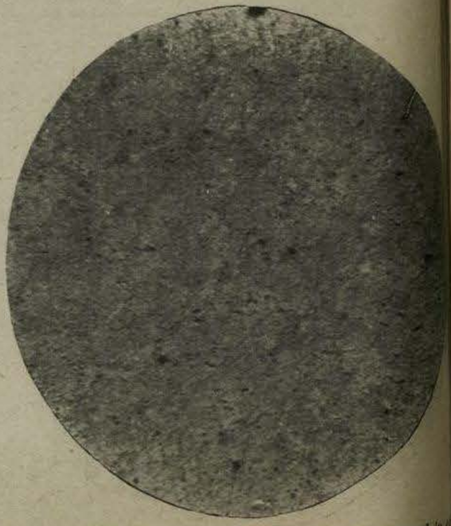


No. 2.—Heated to 900° C. f minutes; water quen from 900° C. Structure resolved under this pow



No. 3.—Heated for 30 minutes at 900° C. Water quenched from 900° C., and afterwards reheated to 450° C. Structure not resolved under this power.

No. 4.—Heated to 900° C. for 30 minutes; quenched in oil from 900° C. Confused structure not resolved under this power.

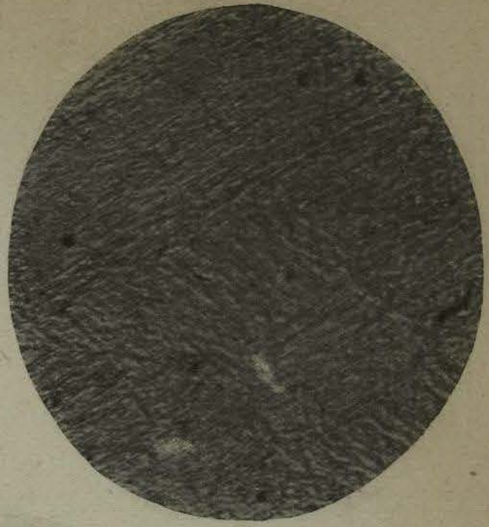


No. 5.—Heated to 900° C. for 30 minutes; quenched in oil from 900° C. and reheated to 450° C. Structure not resolved under this power.

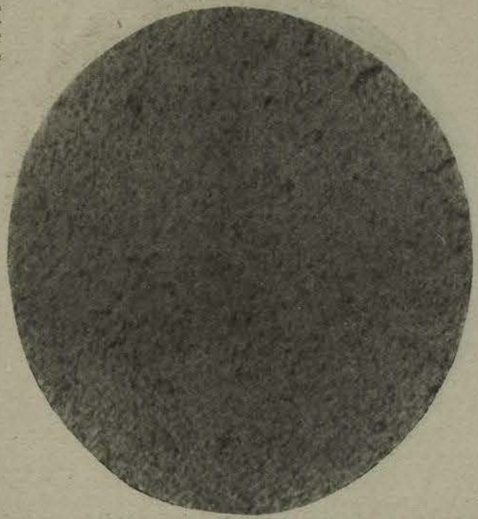
Carbon, ·16.

STEEL No. 1.—MAGNIFICATION 1,000 DIAMETERS.

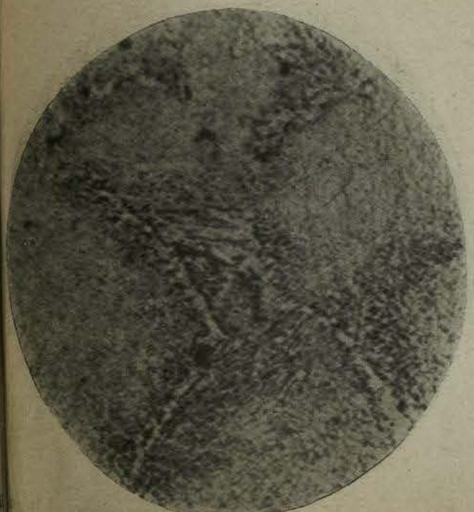
No. 6.—Same section as No. 1, at higher magnification. Annealed for 30 minutes at 900° C.; slowly cooled. Pearlite and Ferrite.



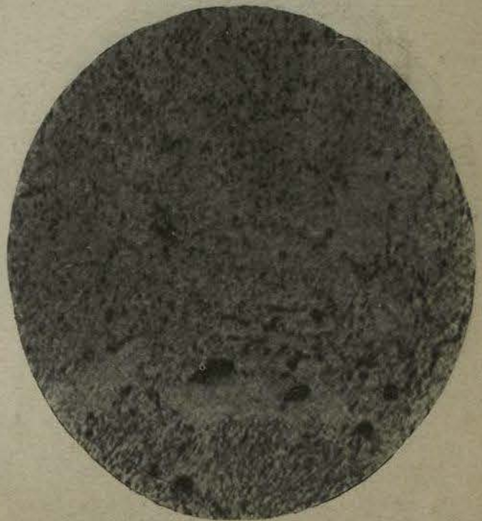
No. 7.—Same section as No. 2. Heated to 900° C. and water quenched. Martensitic structure.



No. 8—Same section as No. 3. Reheated to 450° C. after water quenching. Structures not well defined, but shows how Martensitic structure in No. 5 is broken up by reheating.

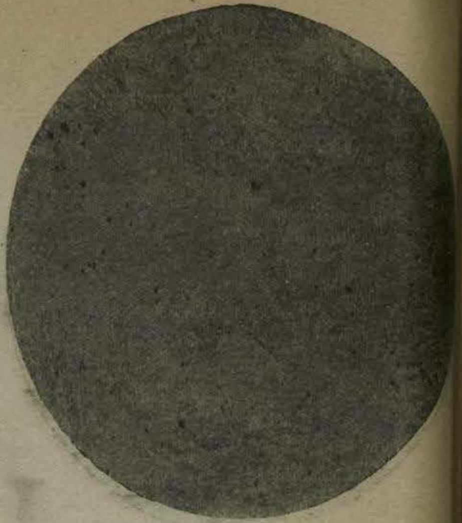


No. 9.—Same section as No. 4. Oil quenched from 900° C. Sorbitic structure.

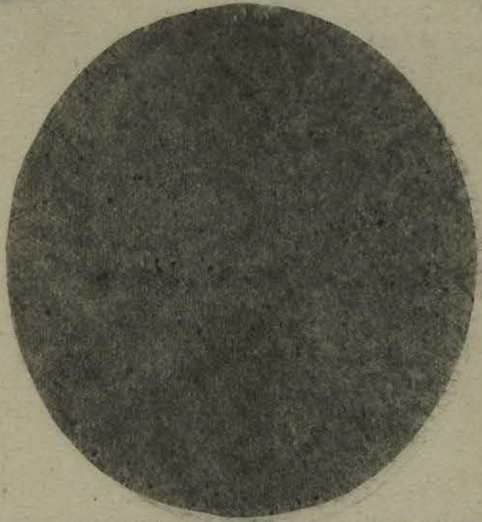


No. 10.—Same section as No. 5. Reheated to 450° C. after oil quenching from 900° C.

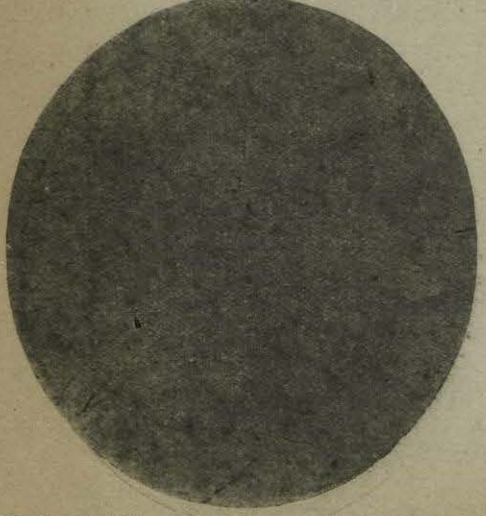
No. 11. — Annealed for 30 minutes at 900° C.; slowly cooled. Pearlite and Ferrite.



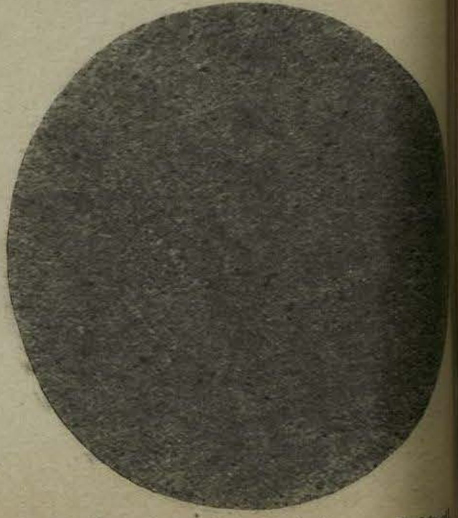
No. 12.—Heated to 900° C. 30 minutes and quenc in water from 900° Structure not resol under this power.



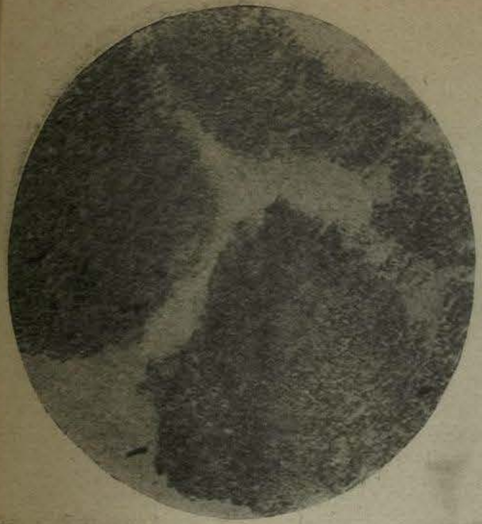
No. 13.—Heated to 900° C. for 30 minutes. Water quenched from 900° C. and afterwards reheated to 450° C. Structure not resolved under this power.



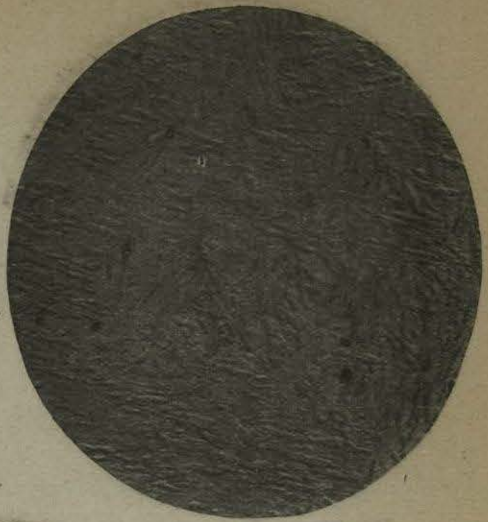
No. 14.—Heated to 900° C. and quenched in oil from 900° C. Confused structure not resolved under this power.



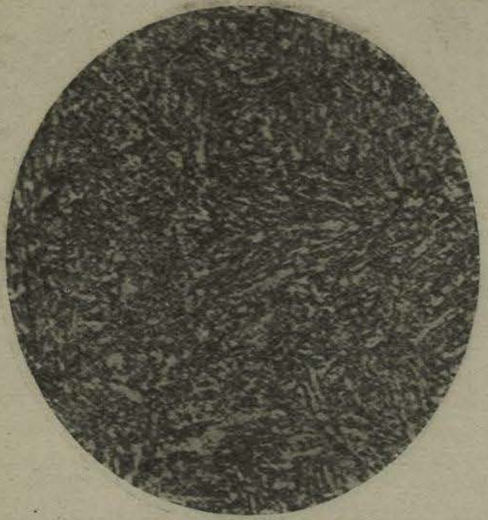
No. 15.—Heated to 900° C. for 30 minutes, quenched in oil from 900° C., and reheated to 450° C. Structure not resolved under this power.



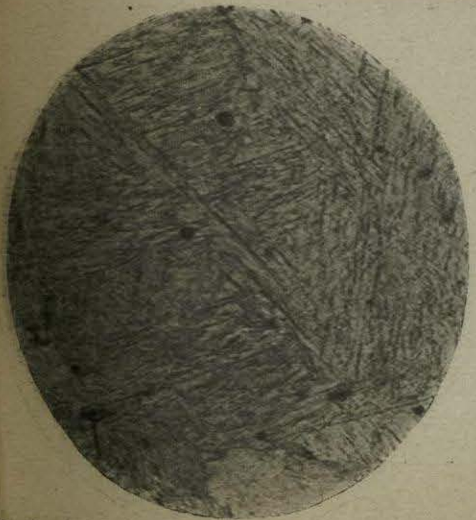
No. 16.—Same section as No. 11. Annealed and slowly cooled. Well-developed Pearlite and Ferrite.



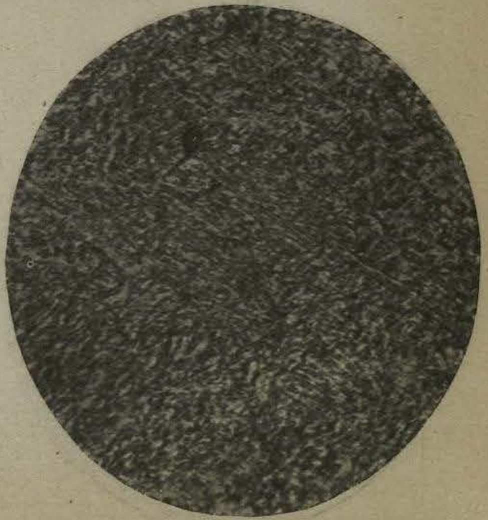
No. 17.—Same section as No. 12. Quenched in water from 900° C. Martensitic structure.



No. 18.—Same section as No. 13. Reheated to 450° C. after water quenching. Showing breaking up of Martensitic structure. Production of intermediate structure between Martensite and Pearlite.



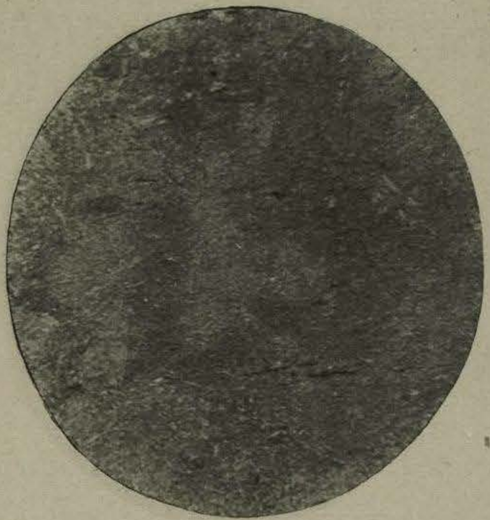
No. 19.—Same section as No. 14. Oil quenched from 900° C. Structure intermediate between that shown in Nos. 17 and 18. Approaching Martensitic



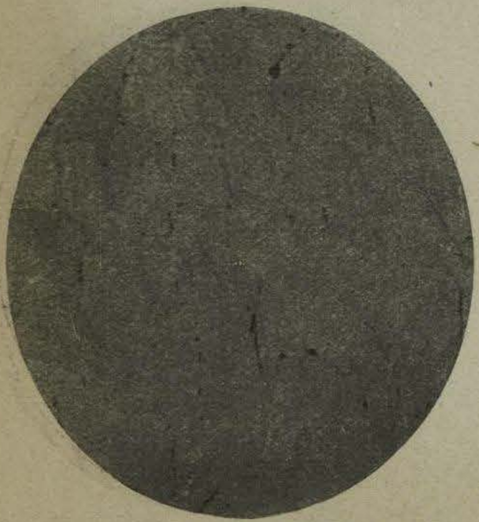
No. 20.—Same section as No. 15. Reheated to 450° C. after oil quenching. Intermediate structure between Martensite and Pearlite, very similar to No. 18.

No. 21.—Annealed for 30 minutes at 900° C.; slowly cooled. Pearlite structure not resolved under this power.

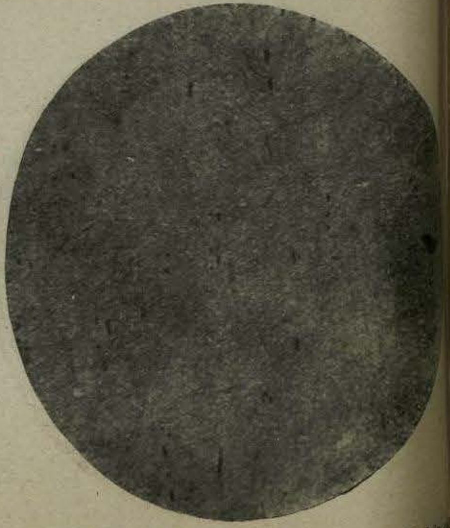
No. 22.—Heated to 900° C 30 minutes, and quen in water from 900 Structure not reso under this power.



No. 23.—Heated to 900° for 30 minutes. Water quenched from 900° C., and afterwards reheated to 450° C. Structure not resolved under this power.

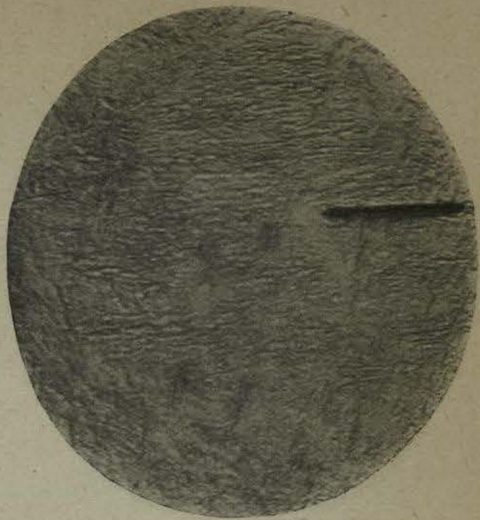


No. 24.—Heated to 900° C., and quenched in oil from 900° C.

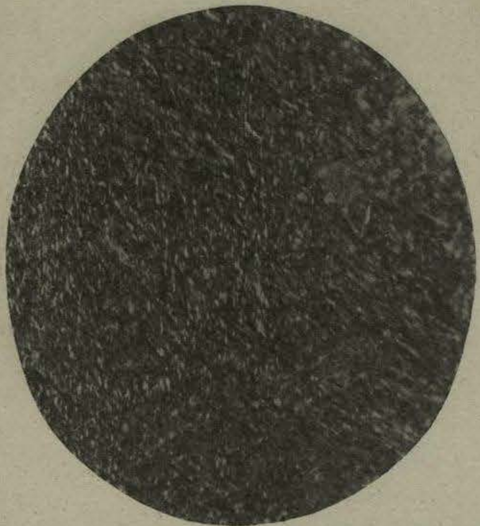


No. 25.—Heated to 900° C. for 30 minutes, quenched

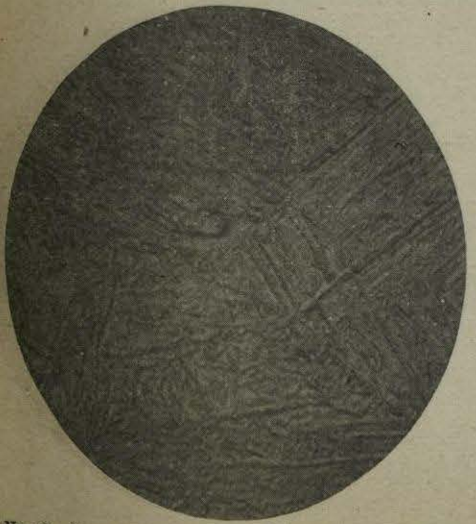
No. 26.—Same section as No. 21. Annealed and slowly cooled. Well-developed Pearlite; saturated steel.



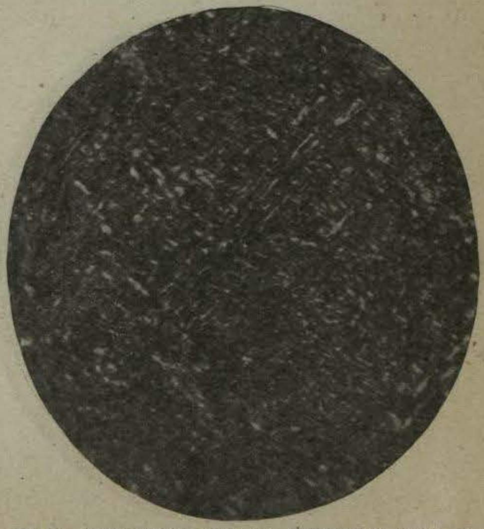
No. 27.—Same section as No. 22. Quenched in water from 900° C. Martensitic structure.



No. 28.—Same section as No. 23. Reheated to 450° C. after water quenching. Showing breaking up of Martensitic structure and production of intermediate structure between Martensite and Pearlite.



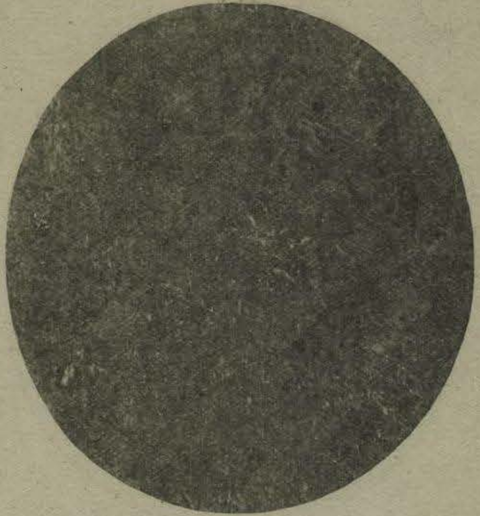
No. 29.—Same section as No. 24. Oil quenched from 900° C. Structure intermediate between that shown in Nos. 27



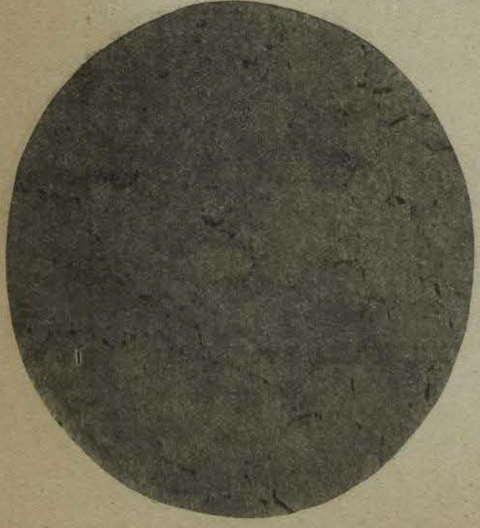
No. 30.—Same section as No. 25. Reheated to 450° C. after oil quenching. Intermediate structure between Martens-

No. 31.—Annealed for 30 minutes at 900° C.; slowly cooled. Structure not clearly defined, but thin bands of Cementite just perceptible.

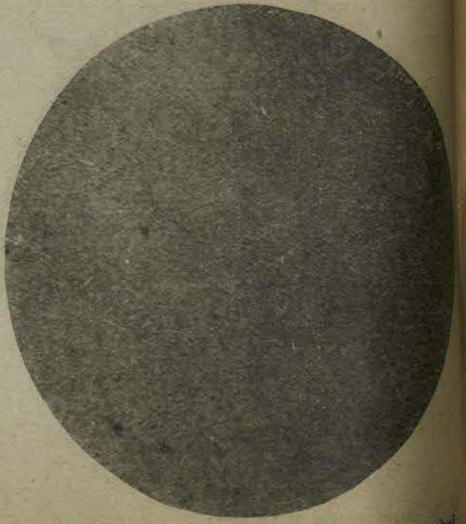
No. 32.—Heated for 30 mi
utes; water quench
from 900° C. Struct
not resolved under th
power.



No. 33.—Heated for 30 minutes at 900° C.; water quenched from 900° C. and afterwards reheated to 450° C. Confused structure not resolved under this power.

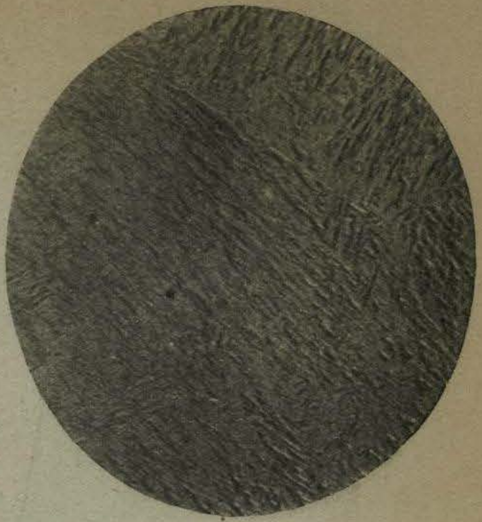


No. 34.—Heated to 900° C. for 30 minutes; quenched in oil at 900° C. Confused structure not resolved under this

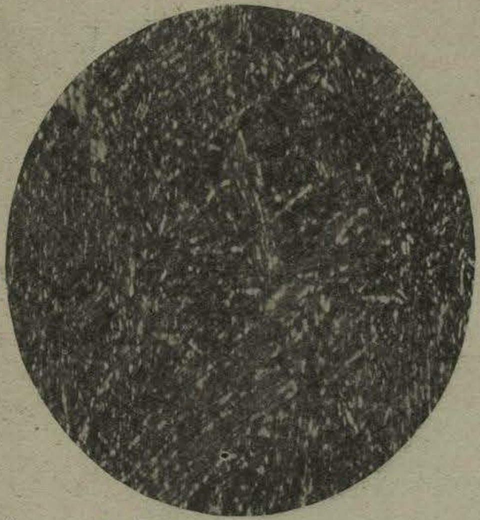


No. 35.—Heated to 900° C. for 30 minutes; oil quenched from 900° C. and reheated to 450° C. Confused structure

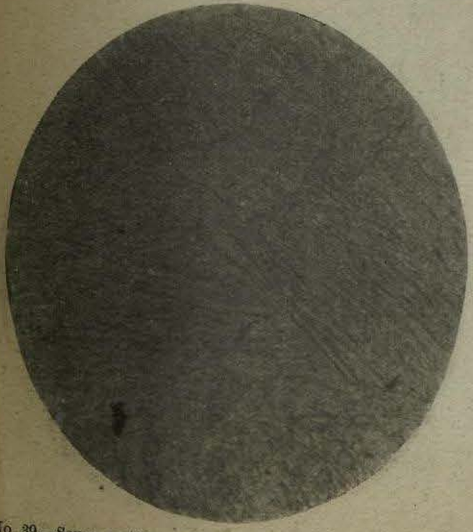
No. 36.—Same section as No. 31. Annealed to 900° C. Well-developed Pearlite and Cementite.



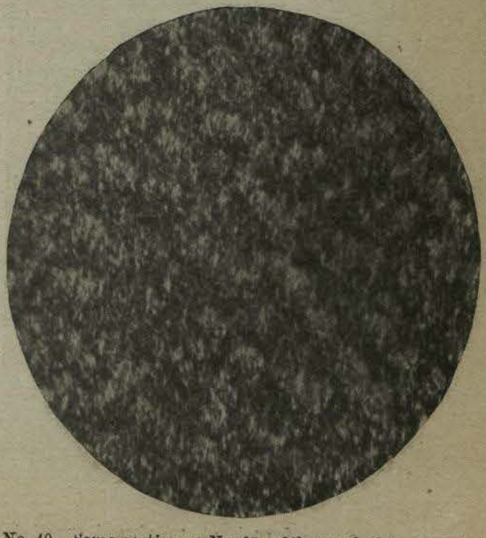
No. 37.—Same section as No. 32. Water quenched from 900° C. Martensitic structure.



No. 38.—Same section as No. 33. Water quenched from 900° C., afterwards reheated to 450° C. Intermediate structure between Pearlite and Martensite.



No. 39.—Same section as No. 34. Oil quenched from 900° C. Semi-Martensitic structure.

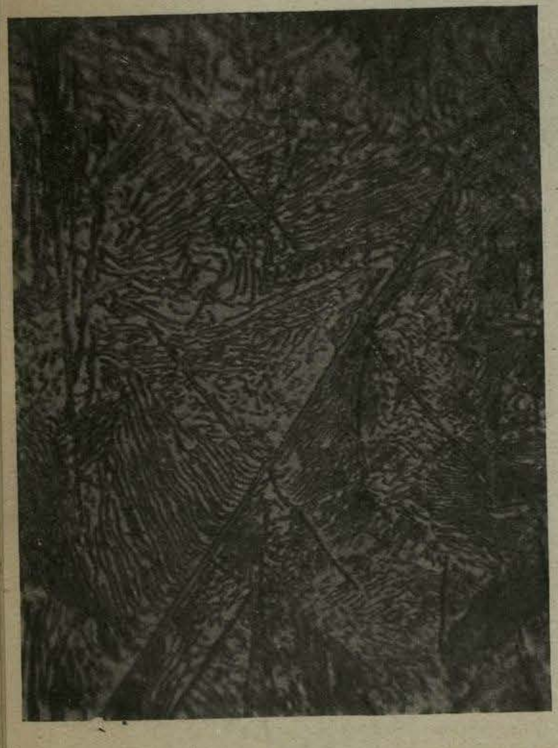


No. 40.—Same section as No. 35. Oil quenched from 900° C. and reheated to 450° C. Sorbitic structure.

HIGH CARBON STEELS.

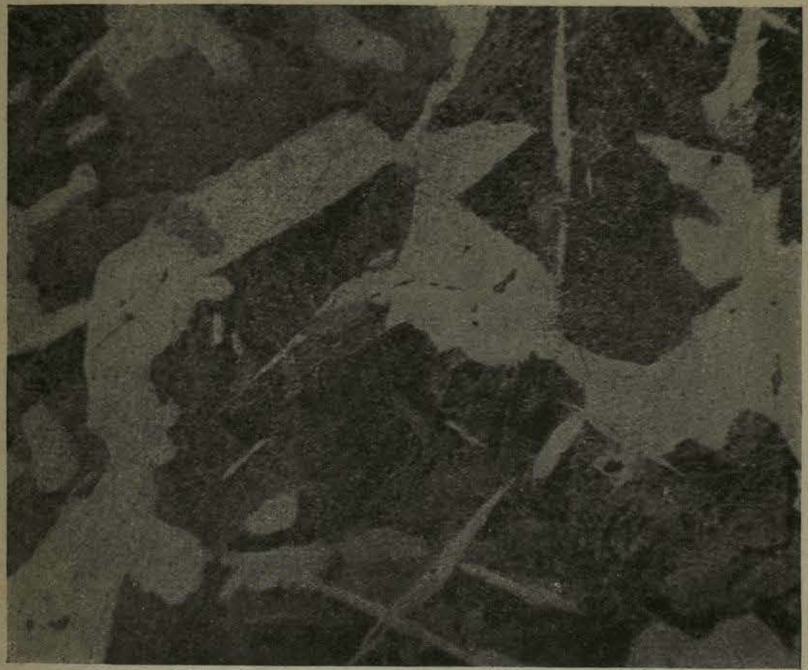
1·5 per cent.

No. 41.—1·5 Carbon from ingot as cast. Magnification 100 diameters.



No. 42.—1·5 Carbon Steel from ingot, rolled and annealed. Typical structure, Pearlite with Cementite bands and some segregated Cementite. Magnification 1,000 diameters.

No. 43.—1·5 Carbon Steel from ingot, annealed; sho
more segregated Cementite. Magnification 1,000 diame



No. 44.—Steel Casting, as cast. Magnification 100 diameters.

No. 45.—Steel Casting, annealed. Magnification 100 diameters.

CAST STEEL.—SECTION SHOWING ORIGINAL MICROSTRUCTURE.

Carbon, 0·328 per cent.

No. 46.—As Cast. Magnification 100 diameters.

CAST STEEL.—SHOWING EFFECT OF ANNEALING ON MICROSTRUCTURE.

Carbon, 0·328 per cent.

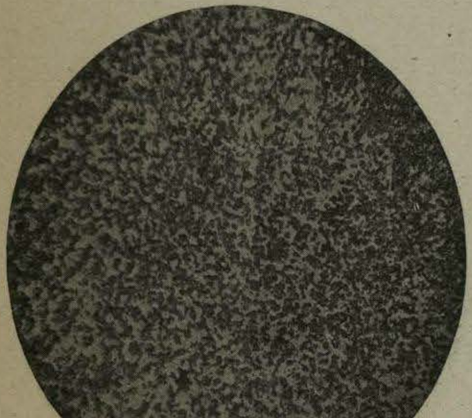
No. 47.—Same Section as 46, annealed at 900° for 20 minutes. Magnification 100 diameters.

PHOTOGRAPHS ILLUSTRATING CHANGES PRODUCED IN MICROSTRUCTURE AND MECHANICAL PROPERTIES BY HEAT TREATMENT. BARS 1½ ROUNDS. MAGNIFICATION 50 DIAMETERS.

ANALYSES.

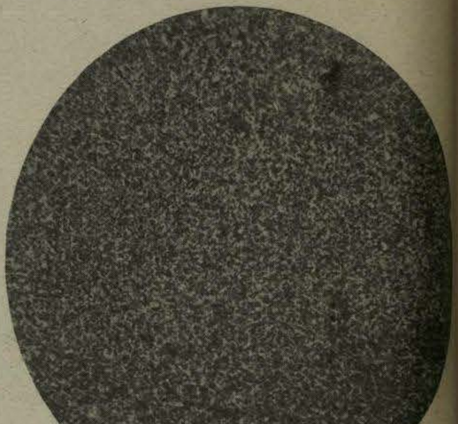
Carbon, 0·180; Silicon, 0·055; Sulphur, 0·055; Phosphorus, 0·071; Manganese, 0·500.

Microsections cut midway between centre and outside.



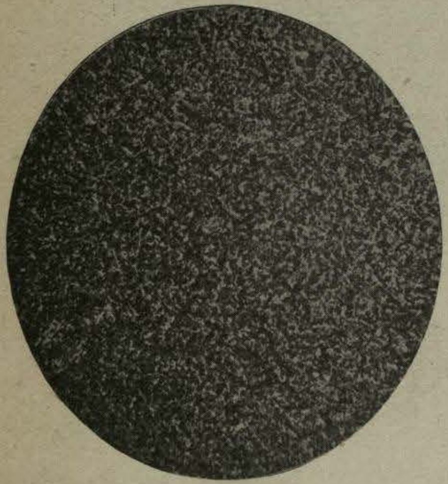
No. 48.—*As Rolled.*

Tensile stress, . .	29·8 tons per square inch.
Elastic limit, . .	15·1 " "
Elongation in 3 ins., .	33·3 per cent.
Reduction of area, .	57·6 "



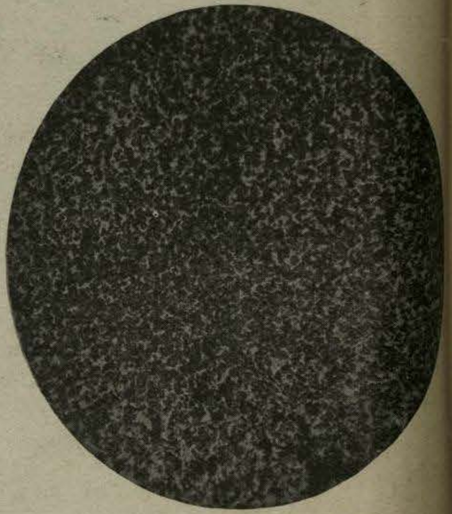
No. 49.—Heated to 740°-760° for 30 minutes, and cooled in ashes. Very fine structure, Ferrite and Pearlite intimately mixed.

Tensile stress, . .	29·0 tons per square inch.
Elastic limit, . .	15·2 " "
Elongation in 3 ins.,	38·0 per cent.
Reduction of area, .	61·0 "



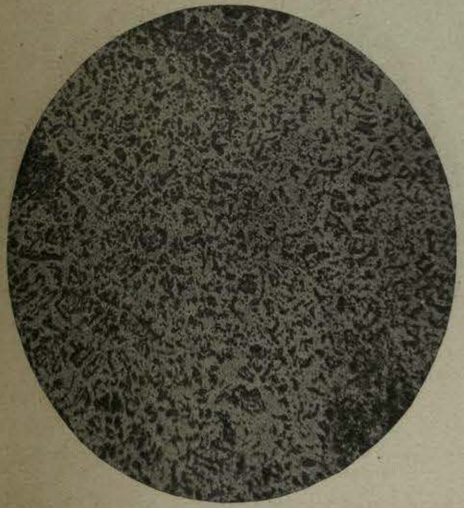
No. 50.—Heated to 820° for 20 minutes, and cooled in ashes. Structure not quite so fine as in No. 49.

Tensile stress, . .	29·1 tons per square inch.
Elastic limit, . .	14·7 " "
Elongation in 3 ins.,	38·3 per cent.
Reduction of area, .	58·3 "



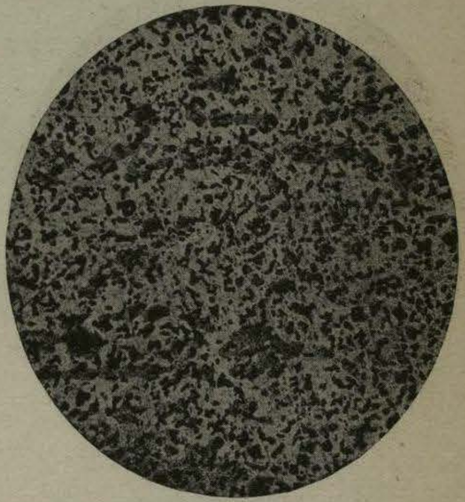
No. 51.—Heated to 820° for 1¾ hours. Structure slightly coarser than No. 50.

Tensile stress, . .	28·6 tons per square inch.
Elastic limit, .	14·8 " "
Elongation in 3 ins.,	39·1 per cent.
Contraction of area,	62·3 "



No. 52.—Heated to 1,000° C. for 15 minutes and cooled in ashes; showing increased size of Ferrite grains.

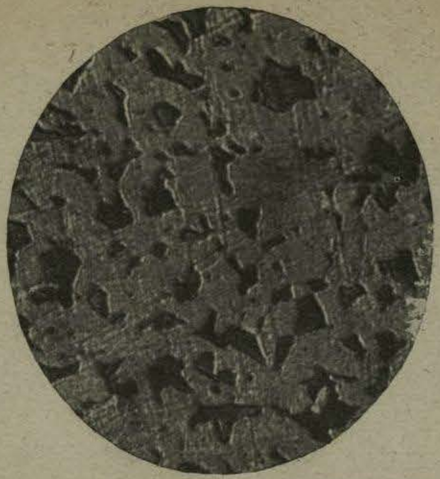
Tensile stress, . .	28·1 tons per square inch.
Elastic limit, . .	14·2 " "
Elongation in 3 ins.,	35·7 per cent.
Reduction of area, .	56·3 "



No. 53.—Heated to 1,160° C. for 5 minutes and cooled in ashes. Ferrite grains considerably increased in size.

Tensile stress, . .	27·3 tons per square inch.
Elastic limit, . .	14·1 " "
Elongation in 3 ins.,	33·8 per cent.
Reduction of area, .	53·1 "

Although the differences in the mechanical properties are not greatly affected, it will be noticed that heating to 1,000° C. reduces both the tensile stress and elastic limit, and elongation, and this is more marked at 1,160° C. Had the heat treatment been prolonged for an hour instead of only being maintained for a few minutes, it is probable that these results would have been much more marked. Heating to 750°, or at all events to 820°, seems to give the best results and to insure the highest elastic limit combined with greatest elongation, and prolonging the heating does not seem to appreciably effect the mechanical properties, as shown in No. 51. The above illustrations, from a paper by Mr. Campion, were reproduced from blocks kindly lent by the Council of the West of Scotland Iron and Steel Institute.



No. 54.—Bar as rolled 1½ inches diameter. Magnification 150 diameters.

Carbon,	0·180
Silicon,	0·055
Sulphur,	0·055
Phosphorus,	0·071
Manganese,	0·560

Maximum stress,	29·8 tons per square inch.
Elastic limit,	15·4 ,, ,,
Elongation in 3 inches,	33·3 per cent.
Reduction of area,	57·6 ,,

Bent over through 180° over radius of 2 inches without fracture.

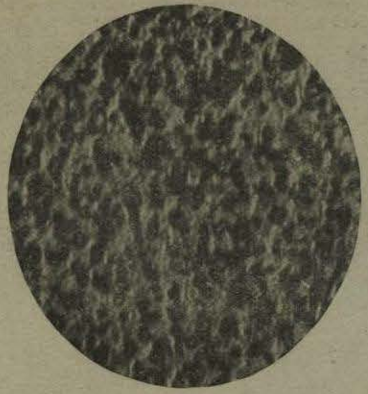
No. 55.—Same bar after heating for 36 hours packed in lime at a temperature of about 1,000° C., and cooling slowly for 32 hours. Magnification 150 diameters.

Maximum stress,	27·2 tons per square inch.	Elongation in 3 inches,	36·0 per cent.
Elastic limit,	14·2 ,, ,,	Reduction of area,	57·6 ,,

Brittle under shock. Broke under two or three blows with a hammer.

Important to note that, although results in tensile machine excellent, material was brittle under sudden shock.

Carbon,	0·190
Silicon,	0·070
Sulphur,	0·044
Phosphorus,	0·053
Manganese,	0·453



No. 56.—Bar as rolled 1½ inches diameter bent through 180° over 2 inches radius. Magnification 150 diameters.

No. 57.—Same bar magnified 150 diameters, after removal from box of Siemens furnace slag, into which it had been dropped when the slag was molten and allowed to remain until the slag was cold.

So brittle that it broke with first blow of hammer.

PHOTO-MICROGRAPHS FROM OIL TEMPERED STEEL AXLE 7 INCHES DIAMETER. MAGNIFICATION 150 DIAMETERS.

A section was taken across the diameter of the axle, and one piece was cut from outside, one piece 2 inches from outside, and one from centre.

It will be noticed that Ferrite grains are much larger in the sample from the centre, and in the outside sample the Ferrite is broken up and more diffused through the Pearlite areas. Under higher powers the outside sample is shown to contain a lot of unsegregated Pearlite, or Sorbite, while the Pearlite is more or less laminated in the sample from the centre.

ANALYSIS.

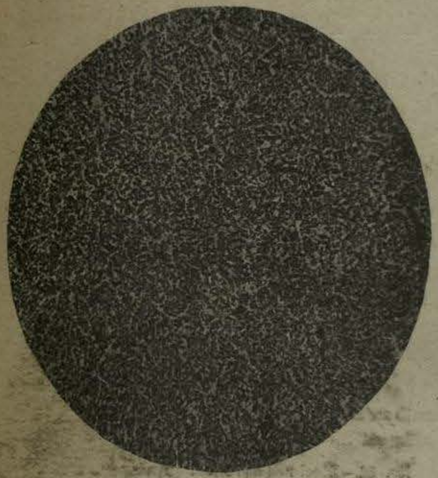
Carbon, ...	0·35	Tensile strength, . .	37·2 tons per square inch.
Sulphur, ...	0·031	Elastic limit, . . .	24·6 ,, ,,
Phosphorus, ...	0·038	Elongation in 3 inches, .	28 per cent.
Manganese, ...	0·660	Reduction in area, . .	49·8 ,,

No. 58.—Sample from the outside.

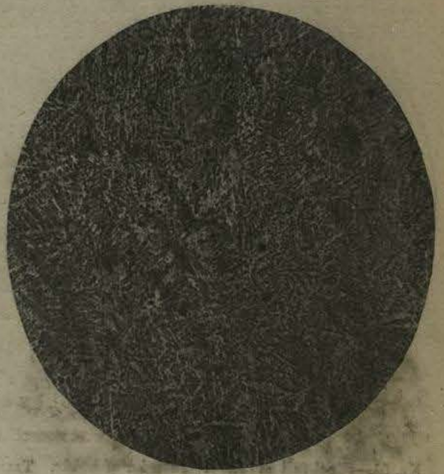
No. 59.—Sample taken 2 inches from outside.

No. 60.—Sample from the centre.

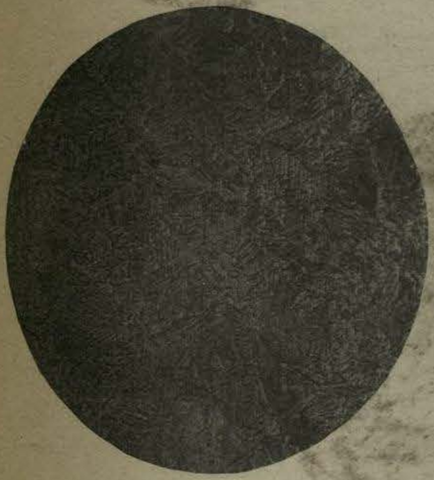
PHOTO-MICROGRAPHS SHOWING EFFECT OF FINISHING TEMPERATURE AND HEAVY AND LIGHT FORGING RESPECTIVELY ON SIZE OF GRAIN. MAGNIFICATION 50 DIAMETERS.



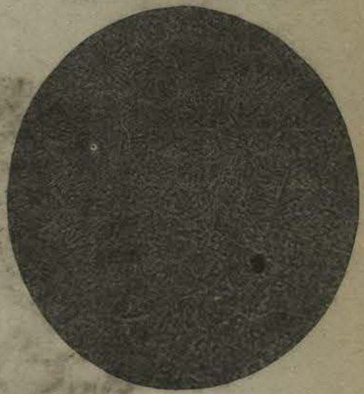
No. 61.—2-inch billet forged to ¾ inch square, finished at dull red heat.



No. 62.—Piece same billet, No. 61, forged to same size, finished just below a yellow heat.



No. 63.—Same billet forged to 1 inch square by a *small* number of heavy blows, finished just below yellow heat.



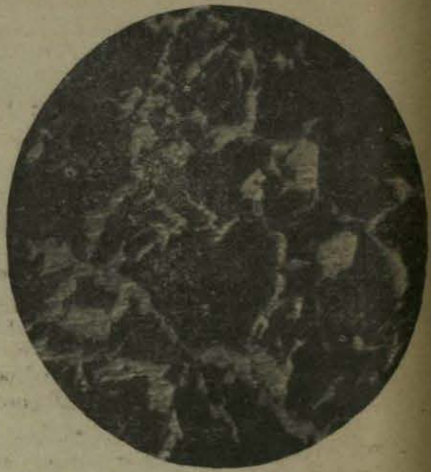
No. 64.—Same billet forged down to 1 inch square by a *large* number of light blows.

PHOTO-MICROGRAPHS OF TWO RAILS AND CEMENT BAR.

No. 65.—Steel rail as rolled. Interior of heads. Transverse section. Magnification 150 diameters.

Carbon,	0·363
Silicon,	0·042
Sulphur,	0·044
Phosphorus,	0·055
Manganese,	0·295

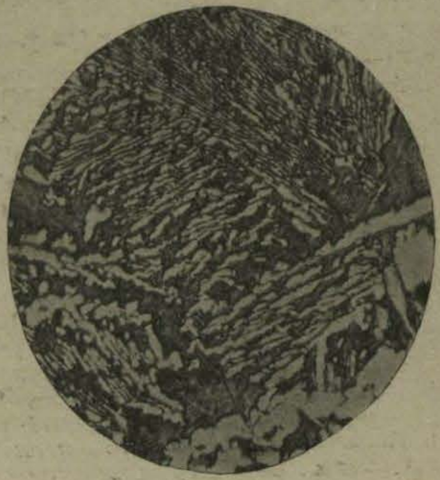
Example of low Carbon and low Manganese steel rail.



No. 66.—Steel rail as rolled. Transverse section. Magnification 150 diameters.

Carbon,	0·489
Silicon,	0·084
Sulphur,	0·050
Phosphorus,	0·069
Manganese,	0·970

Fairly high Carbon and high Manganese rail.



No 67.—Cement bar. Showing Pearlite and Cementite. Magnification 150 diameters.

APPENDIX I.

SPECIFICATIONS.

AMERICAN SPECIFICATIONS.

THE standardisation of specifications for steel rails, tires, axles, castings, forgings, structural steel, boiler plates, &c., has received considerable attention since 1882, when the International Association for Testing Materials was originated.

The American section of this Association was organised in 1898, and was superseded by the American Society for Testing Materials in 1902. This Society publishes a Year-Book devoted chiefly to the publication of the standard specifications and standard methods adopted by the Society.

The following specifications have been adopted by this Society, and it will be seen that, with regard to chemical composition, the amount of Carbon is not generally specified when a tensile test is required, the percentage of constituents other than Phosphorus and Sulphur being left to the manufacturer. In some cases, however, the amounts of Silicon and Manganese are also specified.

It has been recognised that, for the same chemical composition, steel produced in the Basic open hearth is softer than acid Bessemer steel, and it is quite safe to take higher Carbons, especially if, at the same time, a lower percentage of Phosphorus is insisted upon.

AMERICAN STANDARD SPECIFICATIONS, TEST PIECES, AND METHODS OF TESTING IRON AND STEEL, ADOPTED BY COMMITTEE No. 1 OF THE AMERICAN SECTION OF THE INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

The Committee recommends the following as the general requirements which international specifications should include:—

Process of Manufacture.—The process or processes of manufacture of a steel for a given purpose should be specified, but the details of the process should be left to the manufacturer, as a satisfactory product is produced by methods of manufacture varying in different countries.

The proportions of certain of the chemical constituents, especially Sulphur and Phosphorus, should be specified to be within certain limits, and limits should be prescribed to all physical properties which determine the suitability of the steel for the purpose intended.

The number and location of the test pieces should also be specified, the general methods of determining the physical properties specified given, and how the sample for chemical analysis should be taken.

The specifications should also contain clauses governing the required finish and branding of the material, and a clause granting the inspector the necessary facilities to see that the provisions of the specification are carried out.

For steel rails, the following clause may be inserted:—

"The entire process of manufacture and testing shall be in accordance with the best current practice, special care being given to the following instructions:—Ingots shall be kept in a vertical position in pit heating furnaces; no bled ingots shall be used; sufficient material shall be discarded from the top of the ingot to insure sound rails."