O T T A W A   September 25th, 1941.

R E P O R T

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1075.

Report on Malleable Iron Universal Carrier Track Links.

BUREAU OF MINES
DIVISION OF METALLIC MINERALS

ORE DRESSING AND
METALLURGICAL LABORATORIES

CANADA
DEPARTMENT
OF
MINES AND RESOURCES
MINES AND GEOLOGY BRANCH

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Purpose of Investigation:

Since the comparatively recent increase in production of malleable iron castings for Universal carrier track links, serious difficulties have been encountered which have led to the rejection of a fairly high percentage of the finished products. The experimental work covered by this report was undertaken with a view to improving present practice.

Present Heat-Treatment Practice:

The present heat-treatment practice at the plant of the International Harvester Company of Canada Limited, Hamilton, Ontario, is as follows:

"The white iron cast links are piled up on each other (about 10,000 in all, i.e., 14 tons of metal) and heated to 1700° F. The time taken to attain this temperature is approximately 40 hours. The castings are held between 1600° - 1700° F. for a period of from 40 to 50 hours and then cooled to 1400° F. in 10 hours. From 1400° to 1200° F. the total time taken is 20 to 30 hours.

"During the annealing cycle, the atmosphere is kept sufficiently high in carbon dioxide to create a decarburizing atmosphere and the gas generator pressure is held fairly constant till the end of the cycle. The cyaniding operation consists of 34 minutes' preheating at 1200° F., 34 minutes in 35 per cent Parkcase cyanide bath at 1600° F. Natural cooled,@ 35 minutes. Low-strength bath, 2 minutes at 1400° F. Oil quench."

@ The cooling is done slowly in a sheet iron box, known as a "dog-house".

Origin of Material:

The track links used in this investigation were supplied by the International Harvester Company of Canada Limited, Hamilton, Ontario. The following two shipments were received during the summer of 1941:

Shipment A, consisting of 73 links, was received on May 27th, 1941, for examination. This shipment, the test work on which is covered by PART I of this report, was made up of the following:

1) 11 links packed in iron ore, from regular pot annealing furnace;

2) 12 links from the top of decarburizing furnace, heat No. 33;

3) 12 links from the bottom of decarburizing furnace, heat No. 33;

4) 12 links from pot annealing furnace, cyanide hardened;

5) 12 links from top of decarburizing furnace, heat No. 33, cyanide hardened;

6) 12 links from bottom of decarburizing furnace, heat No. 33, cyanide hardened; and

7) 2 unannealed links as cast.

Shipment B, received on July 3rd, 1941, consisted of 400 links which were to be given an experimental heat treatment and then sent back for testing in the field. Upon completion of the work, on September 6th, these 400 links were returned to the International Harvester Company of Canada Limited at Hamilton, Ontario.

PART II of this report covers the experimental heat treatment of Shipment B.

PART I. - TEST WORK ON SHIPMENT A.

Macroscopic Examination and Radiography:

The links showed no external defects.

Radiographs were taken on 20 links, three from each group and two white cast. No appreciable internal defect (shrinkage, blow-holes, etc.) was noticeable. The X-ray examination was made by L. W. Ball through the facilities of the National Research Council of Canada, Ottawa.

Physical Testing of Links as Received:

Hammer Test.

This test consists in flattening with a heavy hammer the bearing portion at the eye section until a certain deformation is obtained without cracking. A flattening reducing by at least one-third the distance between the inner surfaces at the top and bottom of the hole is considered satisfactory. This test resulted as follows:

1. All the cyanided links coming from the top of the decarburizing furnace gave a very poor deformation at the eye section.
2. Ten links from the regular annealed ore packed and cyanided were tested at the eye with a hammer and gave excellent tests.
3. All of the links coming from the bottom of the decarburizing furnace that were cyanided gave excellent hammer tests.

(Continued on next page)

(Physical Testing of Links as Received, cont'd) -

Bend Test.

Bend tests between 8-inch centres were made. A few typical results follow:

First Series: Regular annealed, in ore packing, cyanided.

Maximum load, pounds	Bend, degrees	Core hardness on tread	Surface hardness
13,000	16°	208-224 Vickers.	File hard.
11,800	12°	" " "	" "

Second Series: Links from the top of the decarburizing furnace, cyanided.

Maximum load, pounds	Bend, degrees	CORE HARDNESS On tread:	On eye portion	Surface hardness
9,900	4°	247-254 Vickers (average)	236-242 Vickers (average)	File hard. 590 Vickers (10-kilogram load)
7,600	1°			
12,350	9°			
10,200	7°			
11,000	4°			

Third Series: Links from the bottom of the decarburizing furnace, cyanided.

Maximum load, in pounds	Bend, degrees	Core hardness on tread	Surface hardness
13,800	11°	210 Vickers	File hard.
11,900	8°	210 "	" "
7,750* (only failure)	~1°		" "

* Dark fracture.

Core Hardness.

Links coming from the top of the charge in the decarburizing furnace averaged 154-177 Vickers (30-kilogram load) core hardness after the annealing cycle prior to cyaniding treatment. Links coming from the bottom of the charge or from the regular ore packing averaged only 121-125 Vickers core hardness.

Microscopical Examination:

Figure 1, magnification X100 (nital etched), shows the decarburized area (about 0.016 in.) on a section taken from a link coming from the top of the load in the annealing furnace, Charge No. 33, prior to any cyaniding treatment. Lamellar pearlite is present in a white ferrite matrix. The dark areas are temper carbon particles. Figure 2, magnification X100 (nital etched), shows the amount of decarburization on a link coming from the bottom of the furnace prior to any cyaniding. As seen in this microphotograph, the ferrite matrix is practically free from pearlite and extends at least 0.020 in. to the nearest temper carbon particle. Links coming from the ore packing revealed a similar structure and the extent of decarburization was about the same.

Excessive lamellar pearlite is present in the core of the top links (Figure 3, nital etched, magnification X100) while the bottom links have a ferrite matrix containing very little lamellar pearlite (Figure 4, magnification X100). Figure 5 makes evident the thin case on a section taken from a top link after cyaniding, while Figure 6 shows the case, which is also rather thin, on a link coming from the bottom of the load; as seen, the structure of the substratum is largely ferritic, while in the cyanided link coming from the top of the charge it contains very little ferrite.

Figures 7 and 8 (magnification X500) show the same portion of a white cast iron prior to annealing, etched respectively with nital and Murakami's reagent. In the latter case the free cementite appears like a dark network while in the former it takes the appearance of a

(Microscopical Examination, cont'd) -

white network on a darker background.

Pieces of this white cast iron were treated as follows:

1. Six hours at 1700° F., cooled in furnace.

   A considerable proportion of free cementite (dark network) still remains in the pearlite matrix containing some dark areas of temper carbon particles which are starting to appear in the structure, as shown in Figure 9, magnification X500, Murakami's etch.

2. Nine hours at 1700° F., cooled in furnace.

   The free cementite is still visible as a dark network in a pearlitic backgrown with some temper carbon particles appearing as dark areas. (Figure 10, magnification X500, Murakami's etch).

3. Twelve hours at 1700° F., cooled in furnace.

   The free cementite network is starting to break. Temper carbon particles are increasing in size. (Figure 11, magnification X500, Murakami's etch).

4. Fifty hours at 1700° F.; furnace cooled.

   The free cementite has practically all disappeared, except for a few rare spots (dark area, regularly shaped). The lamellar pearlite is seen as the background and is due to the relatively fast cooling of the specimen. (Figure 12, magnification X500, Murakami's etch).

5. Several annealed sections from the top and bottom links from Charge No. 33 were examined for free cementite and were found to contain none, showing that the soaking time at 1700° F. was sufficiently long.

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Discussion:

The case on most of the cyanided links received from the International Harvester Company of Canada Limited for examination has an average thickness of 0.005 in. thickness. This rather thin case is what should reasonably be expected for a carburizing time of 34 minutes; increasing this case thickness would probably mean a little better wear but would require a longer time in the first cyaniding treatment, with a corresponding decrease in the rate of production.

The surface of the cyanided links was file-hard, although the usual Vickers method of testing it (using a 10-kilogram load) could not be used with accuracy because of the thin case.

The results obtained from the bend and hammer tests seem to indicate that, although there might be some room for improvement, the heat treatment following the annealing would be appropriate and would not likely be the cause of the increase in the number of link failures experienced at the International Harvester plant. The trouble would seem to originate, rather, from the poor "malleabilizing" of a portion of the charge in the decarburizing furnace. A comparison between Figure 3 and Figure 4 seems to establish definitely that the top links have not the proper annealed structure, since excessive lamellar pearlite is present after the annealing cycle. Due to its greater surface-to-volume ratio and also to its greater solubility, the lamellar pearlite will go into solution in a much shorter time than will the temper carbon particles. During the rather short time taken for cyaniding it looked

(Discussion, cont'd) -

as though the percentage of carbon which will enter the matrix will be dependent chiefly on the amount of pearlite present before the treatment (only a small portion of the carbon would come from the temper carbon). If excessive pearlite is present, the ferrite matrix will be nearly saturated in a very short time, thus forming a high-carbon matrix which would result in the very brittle structure observed after oil-quenching, especially in the thinner sections of the link (eye sections).

Variation of Core Hardness of Castings with Position in Furnace:

The links coming from the top of the furnace charge showed an average core hardness of 154 to 177 Vickers (i.e., 4.5-4.8 mm. Brinell impression with a 10-mm. ball and 3,000 kilograms) while the bottom links were much softer in the core, 121-125 Vickers (i.e., 5.35-5.40 mm. Brinell impression). Since the core hardness in this particular case is a function of the pearlite present in the annealed structure, it may be taken as a criterion to the quality of the annealing treatment. As a rule, any link coming from the furnace and having a core hardness above 140 Vickers (approximately 5.0 mm. Brinell impression) should go back through the annealing cycle.

Possible Cause of Excessive Pearlite During The Malleabilizing Treatment:

Precipitation of carbon, during the last stage of the annealing cycle, will take place only under certain conditions. If the cooling in the critical range is done too fast, the carbides will be left undecomposed and the

(Possible Cause of Excessive Pearlite During Malleabilizing Treatment, cont'd) -

resulting partially annealed structure will be rich in lamellar pearlite. The rate of cooling adopted at the International Harvester Company plant (7 to 10° F. per hour, from 1400° F. to 1200° F.) should be slow enough. It seems, however, by the results obtained from the microscopical examination, that the whole mass of the charge is not cooling down at a uniform rate. An appreciable proportion of the links (the top links) would go through the critical range at a considerably higher rate. The abnormal cooling of the top link might be ascribed to the gases coming into the furnace to create a decarburizing atmosphere. These gases would be at a lower temperature than the furnace and in effect would "quench" the castings which are near the incoming flow.

The following suggestions are put forward as a possible solution to the problem:

1. The gas used in controlling the atmosphere might be preheated to a temperature slightly higher than that of the furnace.
2. The distribution of the gas should be done through several outlets with proper deflecting plates.
3. The pressure of the gas should be reduced to a minimum, i.e., just enough to keep a positive pressure during the last stage of the annealing cycle.

PART II. - EXPERIMENTAL HEAT TREATMENT OF SHIPMENT B.

General Data:

Since the major proportion of the tests were made by heating the casting in cyanide and cooling it in oil, data were obtained on the heating time in cyanide and cooling time in oil. The following was recorded, the Universal Carrier link being immersed in a bath of sufficient capacity to affect very little the temperature of the whole mass and the thermocouple being placed 1/16 in. below the surface of a clean malleable iron link:

- Heating in Cyanide -

Time, in seconds		Temperature, in degrees Fahr.
0	-	80
15	-	458
30	-	965
45	-	1330
60	-	1375
75	-	1410
90	-	1419
105	-	1421
120	-	1427
135	-	1433
150	-	1443
165 (secs.)	-	--

- Cooling Rate in Oil* -

Time, in seconds		Temperature, in degrees Fahr.
0	-	1450
15	-	725
30	-	465
45	-	360
60	-	290
75	-	246
90	-	218
105	-	197
120	-	183
135	-	171
160	-	165
175 (secs.)	-	161°

* Thermocouple at 1/16 in. from surface.

STUDY OF VARIOUS HEAT TREATMENT METHODS FOR MALLEABLE IRON:

Method I.

The well annealed casting is first cyanided at a temperature above the lower critical. It is then cooled, reheated for a short time above the critical, and oil-quenched.

During the first part of the treatment, the following reactions take place:

a) A carbon-nitrogen case is produced; the higher the temperature, the greater the carbon-nitrogen ratio.

b) Some carbon, coming from the precipitated temper carbon particles and from the pearlite contained in the annealed structure, goes into solution in the ferrite matrix of the core.

An air or oil quench may follow, the latter giving a more refined structure and increasing the impact value.

During the last part of the treatment,

a) the core reaches a temperature below and close to the critical point (this is equivalent in effect to a high-temperature tempering of the core); and

b) the case, rich in carbon and nitrogen, attains a temperature above its change point, with a consequent hardening upon cooling in oil.

This treatment is based mainly on the difference in change points of the case and core and also on the difference in heating rates of the core and case in a cyanide bath. This fact is made clear by examining the above-mentioned general data on the heating time of the surface portion of the link in cyanide, knowing that the core itself takes from 6 to 8 minutes before attaining the

(Method I, cont'd) -

temperature of the surrounding cyanide.

Typical structures of the core are shown in Figures 13 and 14, photomicrographs at X1500 magnification. In Figure 13 the core has been air-cooled after cyaniding 34 minutes at 1650° F., then oil-quenched after being 2 minutes in cyanide at 1400° F.; in Figure 14 the core has been oil-quenched after cyaniding 34 minutes at 1650° F., then oil-quenched after being heated 4 minutes in cyanide at 1400° F.

The International Harvester Company of Canada Limited have been producing links by the above method since the beginning of the year. As is seen from the first part of this report, the preliminary annealing operation has to be conducted with considerable care in order to obtain a good final product.

Method II.

The cyaniding is done at a temperature below the critical of the core and is followed by air or oil cooling. A short soak above the lower critical then follows in order to obtain toughness of the core and hardness of the case.

This method is based on the fact that a 50 per cent cyanide bath containing about 5 per cent cyanate will readily produce a case high in nitrogen and relatively low in carbon at a temperature below the critical point (1300° to 1325° F.).

The following typical results were obtained on

(Method II, cont'd) -

one of the links that were cyanided at 1325° F. for 34 minutes, cooled in air, reheated to 1425° F. for 10 minutes, and quenched in oil:

Hammer test: Good.

Surface hardness: 542-548 Vickers (5-kg. load).

Bend test: 10.5 degrees. Maximum load: 11,800 pounds.

Microscopical Examination: Figure 15 shows the nitride martensite case on the ferrite and sorbite substratum, at a magnification of X100.

Two links were cyanided at 1325° F. for $1\frac{1}{2}$ hours in 50 per cent cyanide; one was air-cooled and the other oil-quenched. Both were then reheated to 1400° F. for 10 minutes and oil-quenched.

Results:

Hammer test	Bend, degrees	Maximum load, pounds	Surface hardness, V.H.N.
Excellent	12	9,500	494
Excellent	10	8,200	502

Method III.

The cyaniding is done slightly above the critical temperature of the core (at 1400°F. for 60 minutes) and is followed by an oil quench. The last part of the treatment is an oil quench after a 30-minute heating in cyanide at 1325° F. This method is based on the high nitrogen content of the case obtained at low-temperature cyaniding. Figure 15 shows the case obtained (magnification X100, nital etched).

(Continued on next page)

(Method III, cont'd) -

Results -

Hammer test: Excellent.

Surface hardness: 445 (5-kilogram load), 350 (10-kilogram load).

Bend, in degrees	Maximum load, in pounds
(a) 11.5	12,300
(b) 10.0	11,300

Method IV.

Oil quench and draw. All hardness readings taken on a Vickers machine with a 30-kilogram load.

First Series

Oil-quenched after heating 34 minutes at 1400° F.

a) Draw: 60 minutes at 600° F.

Hammer test: very bad, brittle break.
Surface hardness on the eye portion: 290-299.
Core hardness on the eye section: 554-579.

b) Draw: 60 minutes at 700° F.

Hammer test: bad.
Surface hardness on the eye portion: 171-172.
Core hardness on the eye section: 454-481.

c) Draw: 120 minutes at 800° F.

Hammer test: poor.
Surface hardness on the eye portion: 149-187.
Core hardness on the eye section: 357-366.
Maximum load: 13,600 pounds. Bend: 2 degrees.

d) Draw: 120 minutes at 1100° F.

Hammer test: excellent.
Surface hardness: 192.
Core hardness: Average of 220.
Maximum load: 12,400 pounds. Bend: 6 degrees.

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(Continued on next page)

(Method IV, cont'd) -

Second Series

Oil-quenched after heating in cyanide for 45 minutes.

a) No draw.

Hammer test: very bad, brittle break.
Surface hardness on
eye portion: 238.
Core hardness on
eye section: 635.

b) Draw: 700° F. for two hours.

Hammer test: poor.
Surface hardness on
eye portion: 216-232.
Core hardness on
eye section: 246-260

c) Draw: 900° F. for two hours.

Hammer test: very good.
Surface hardness on
eye portion: 238.
Core hardness on
eye section: 353-362.
Maximum load: 14,600 pounds. Bend: 1 degree.

d) Draw: 1000° F. for two hours.

Hammer test: very good.
Surface hardness on
eye portion: 163.
Core hardness on
eye section: 247-256.
Maximum load: 14,100 pounds. Bend: 7 degrees.

e) Draw: 1100° F. for two hours.

Hammer test: very good.
Surface hardness on
eye portion: 130.
Maximum load: 11,000 pounds. Bend: 6 degrees.

-

Third Series

Oil-quenched after heating in cyanide at 1550° F. for 34 minutes.

(Continued on next page)

(Method IV, cont'd) -

(Third Series, cont'd) -

a) Draw: 800° F. for two hours.

Hammer test: good.
Surface hardness on eye portion: 200.
Core hardness on eye section: 336.
Maximum load: 16,150 pounds. Bend: About 1 degree.

b) Draw: 900° F. for two hours.

Hammer test: excellent.
Surface hardness on eye portion: 125-135.
Core hardness on eye section: 331.
Maximum load: 11,800 pounds. Bend: 1 degree.

c) Draw: 1000° F. for two hours.

Hammer test: poor.
Surface hardness: 135-141.
Core hardness on eye section: 282.
Maximum load: 10,800 pounds. Bend: 1½ degrees.

d) Draw: 1100° F. for two hours.

Surface hardness: 175-196.
Core hardness: Average 230.
Maximum load: 10,650 pounds. Bend: 14 degrees.

Method V.

Austempering of Blackheart Malleable

A mixture of salt, consisting mainly of sodium hydroxide, potassium hydroxide and sodium carbonate, was used in order to obtain a medium the cooling rate of which would be intermediate between water and quenching oil at a temperature range of 1400° F. It was found that the quenching in the above medium was accomplished without any trouble. In fact, the operation was much easier than oil-quenching; with proper care, no splashing, no smoke, no foaming occurred.

(Continued on next page)

(Method V, cont'd) -
(Austempering of Blackheart Malleable, cont'd) -

Even at 550° F., the bath is very fluid. The quenched articles come out of the bath clean and the mechanical losses are reduced to a minimum--a loss of only about 3 pounds was experienced during the treatment of more than 350 links, i.e. nearly a thousand pounds of small castings. After the quench, the small amount of salt left on the casting is washed away in water.

A number of tests were made in order to find the austempering treatment which would give a tougher structure to the well annealed link and at the same time keep the surface at a sufficient hardness.

The following data were obtained: (The treatment comprises only a direct quench from cyanide into the salt bath. Hardness readings are given in Vickers, with a 30-kilogram load) -

1. 34 minutes in cyanide at 1400° F. Quenched into salt at 500° F. for 30 minutes.

Hammer test: excellent.
Maximum load: 12,500 pounds.
Bend: 4 degrees.
Surface hardness on eye portion: 216.
Core hardness on eye section: 345.

2. a) 34 minutes in cyanide at 1400° F. Quenched into salt at 600° F. for 30 minutes.

Hammer test: excellent.
Hardness: Surface, on eye portion: 321-305.
Core, on eye section: 295-325.
" , on tread " : 270-295.

Maximum load, in pounds:	--	13,700	13,100
Bend: --	--	6 degrees	5 degrees

Impact test (no notch) on a 0.350 inch square bar = 21 ft.lb.

(Continued on next page)

(Method V, cont'd) -
(Austempering of Blackheart Malleable, cont'd) -

b) 60 minutes in cyanide at 1400° F. Quenched into salt at 600° F. for 30 minutes.

Hammer test: excellent.
Hardness:
Case, on eye portion: 323.
Core, on eye portion: 308.
Maximum load: 13,000 pounds.
Bend: 4 degrees.

3. 34 minutes in cyanide at 1400° F. Quenched into salt at 800° F. for 30 minutes.

Hammer test: excellent.
Hardness:
Surface, on eye portion: 142.
Core, on eye section: 278.
Maximum load: 10,200 pounds.
Bend: 8 degrees.

4. 34 minutes in cyanide at 1400° F. Quenched into salt at 900° F. for 30 minutes.

Hammer test: excellent.
Hardness:
Case, on eye portion: 144.
Core, on eye portion: 212.
Maximum load: 10,700 pounds.
Bend: 7 degrees.

5. 34 minutes at 1500° F. Quenched into salt at 500° F. for 30 minutes.

Hammer test: excellent.
Hardness:
Surface, eye portion: 294.
Core, eye portion: 325.
Maximum load: 11,900 pounds.
Bend: 5 degrees.

6. 34 minutes at 1500° F. Quenched into salt at 600° F. for 30 minutes.

Hammer test: excellent.
Hardness:
Surface, on eye portion: 274.
Core, eye portion: 360.
Maximum load: 12,000 pounds.
Bend: 3 degrees.

(Continued on next page)

(Method V, cont'd) -
(Austempering of Blackheart Malleable, cont'd) -

7. 34 minutes at 1500° F. Quenched into salt at 700° F. for 30 minutes.

Hammer test: excellent.
Hardness:
Surface, eye portion: 224.
Core, eye portion: 331-357.

8. 34 minutes at 1600° F. Quenched into salt at 900° F. for 30 minutes.

Maximum load: 8,500 pounds.

Remark: Cracks developed during quenching.

Other Austempering Treatments.

A. 60 minutes in 50 per cent cyanide at 1400 to 1425° F. Quenched into salt at 300° F. for 30 minutes. (The quenching bath was a mixture of potassium and sodium nitrites, which is not to be recommended in connection with cyanide).

Hammer test: excellent.
Surface hardness: 657 Vickers, 10-kilogram load.
Core hardness of eye section: 280.
" " " tread " : 258.
Maximum load: 11,700 pounds.
Bend: 10 degrees.

Microscopic examination:

The fine martensitic structure of the case is shown in Figure 16, magnification X100.

B. 34 minutes in 50 per cent cyanide at 1400° F. Quenched into salt at 300° F. for 30 minutes. (Quenching bath same as in A).

(Continued on next page)

(Other Austempering Treatments, cont'd) -

Treatment B, cont'd -

Hammer test: excellent.
Surface hardness: 498.
Core hardness on
eye section: 209.
Core hardness on
tread section: 202.
Maximum load: 12,100 pounds.
Bend: 11.5 degrees.

Microscopic examination:

The nitride-martensite case is shown in Figure 17, magnification X100. The core structure obtained in the isothermal transformation at 300° F. is given in Figure 18, magnification X500. Although the very fine bainite structure is not much resolved in that microphotograph, it can be differentiated from the untransformed fine pearlite (darker etching).

DISCUSSION OF HEAT TREATMENT METHODS:

The relative merits of each of these different methods cannot be discussed without first examining the relationship between wear and structural condition. Wear resistance is not always a direct function of hardness.

I. For straight abrasive wear, the highest possible hardness (as measured by the Vickers method) will give the longest life. In this case, a nitrided surface will give best service.

II. When, however, resistance to abrasion is needed under highly stressed conditions, a certain ductility is

(PART II, cont'd) -
(Discussion, cont'd) -

required, even at the expense of high hardness. In this latter case, as when, for instance, parts must withstand considerable battering (as would track links), the structural conditions of the surface will become the most important factor governing wear. The austenitic structure has proven to be an ideal wear-resisting structure. Graphite and temper carbon particles also are known to prolong the wear. This might be a point in favour of using a blackheart malleable link annealed in a neutral or slightly carburizing atmosphere and austempered from a cyaniding bath to harden and toughen the structure.

Method I, used at the present time by the International Harvester Company of Canada Limited, Hamilton, Ontario, has proven satisfactory. It gives a file-hard surface and a tough core at the tread portion when the link is properly annealed and treated. However, under service it was observed that many of the breakages developed at the eye portion bearing. Due to its comparatively smaller section, this particular part of the link has a tendency to become embrittled during the heat treatment. All indications are that this same defect was also experienced with the British-made whiteheart malleable.

The method using a subcritical heat-treatment in the final step produced an appreciably higher bend on the tread portion, although the elastic limit and the surface hardness of the material were considerably reduced. Links produced by this method might well undergo considerable stretch during service.

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(PART II, cont'd) -
(Discussion, cont'd) -

The "oil quench and draw" method, as expected, did not give encouraging results. In a general way, the tread portion of the link after the draw remains relatively too brittle, with an excessive drop in the surface hardness due to the decarburized skin. To sum up, a malleable iron link, oil-quenched and drawn at approximately 1000° F., although tough enough in the core, would eventually show up excessive wear after a short mileage.

Austempering of Blackheart Malleable -

The austempering treatment of properly annealed malleable iron produces remarkable toughness at the weakest points of the link, i.e., at the eye and guide portions. The tread portion, however, does not gain much by this treatment; its structure still has only average strength and ductility. The impact value is increased, however. The core hardness of the eye portion can be improved by the austempering treatment, to 300-325 Vickers, without loss of ductility. In fact, as shown in Figures 19 and 20, a considerable increase over the usual bend obtained was noticeable in the hammer test. The combination of toughness and hardness observed at the eye portion would result in decreasing the wear and the stretch of the link assembly.

As the increase in toughness at the eye portion of the link might not warrant the loss of ductility in the tread portion, it was felt that a trial in the field would give the real merit of the austempering treatment. Four hundred links were cast and annealed by the International Harvester Company of Canada Limited and sent for treatment to the Bureau of Mines, at Ottawa. Unfortunately, the links

(Continued on next page)

(PART II, cont'd) -
(Discussion, cont'd) -

had been decarburized during the annealing operation, leaving a skin of low carbon content.

However, as much pearlite was visible under the microscope in the core of the links as received, the links were given a slow annealing in a carburizing atmosphere in order to free them of any excessive pearlite. The hardness on the core after this treatment averaged 115 to 120 Vickers.

The heat-treatment was as follows: 30 minutes in cyanide at 1400-1450° F.; quench in a salt mixture at 600-650° F. for 30 minutes. It was found that this treatment was very simple and could be made practicable on a large scale. Furthermore, this treatment is rapid and would probably mean a large heat-treating capacity with very little equipment. For typical results obtained, see Method V-2a.

A microphotograph at 3,000 magnification, Figure 21, reveals the bainite structure of a section from the eye portion, some darker areas of untransformed fine pearlite, and a portion of a temper carbon particle (large dark spot). It was noticed, however, that a fair amount of ferrite was still present between the austempered structures of the case and core. If the annealing process of blackheart malleable were done in a properly controlled atmosphere, a higher-carbon surface would likely be obtained (by decreasing the CO_2-to-CO ratio according to temperature or by using an atmosphere rich in hydrocarbons), which would result in a more homogeneous structure of the surface and core.

(PART II, concluded) -

SUMMARY:

Various methods of heat-treating malleable iron, used in connection with Universal Carrier track links, have been developed in order to combine strength, ductility, and wear resistance, required under highly abrasive and stressed conditions.

A new method is also described in which the casting, after being annealed in a neutral or carburizing atmosphere, is austempered. The various possibilities of this method are discussed.

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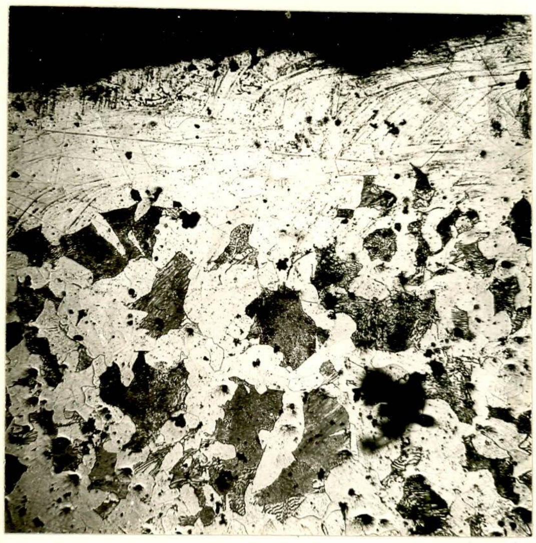
Figure 1.



X100, nital etch.

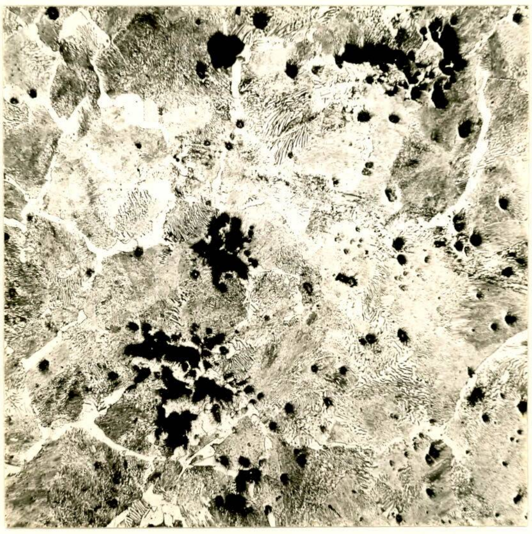
Decarburized area of top link.

Figure 2.

X100, nital etch.

Decarburized area of bottom link.

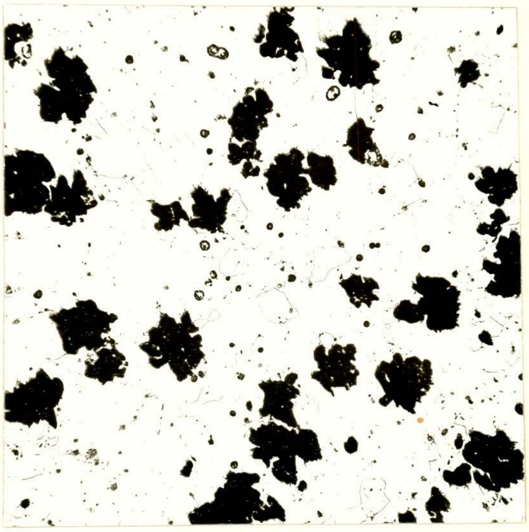
Figure 3.



X100, nital etch.

Core structure of top link.

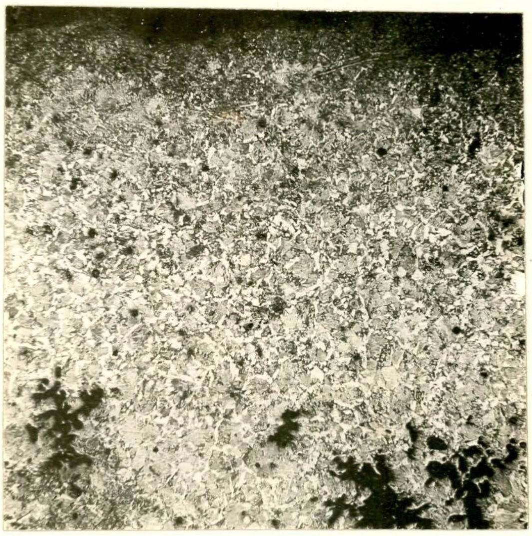
Figure 4.



X100, nital etch.

Core structure of bottom link.

Figure 5.



X100, nital etch.

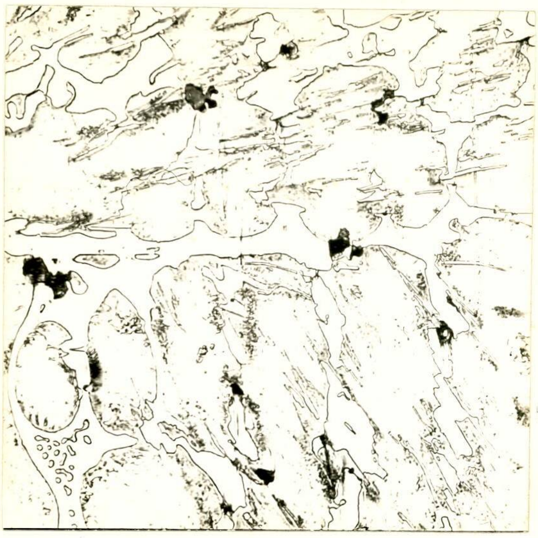
Case on cyanided "top" link.

Figure 6.

X100, nital etch.

Case on cyanided "bottom" link.

Figure 7.



X500, nital etch.

White cast iron.

Figure 8.

X500, Murakami's reagent etch.

White cast iron.

Figure 9.

X500, Murakami's etch.

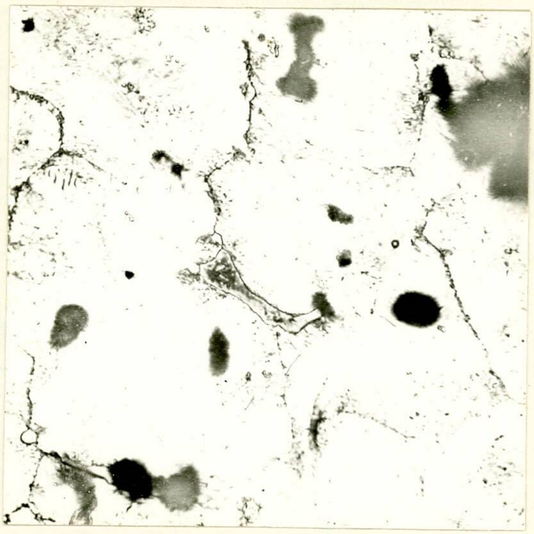
White cast iron after heating 6 hours at 1700° F.

Figure 10.

X500, Murakami's etch.

White cast iron after heating 9 hours at 1700° F.

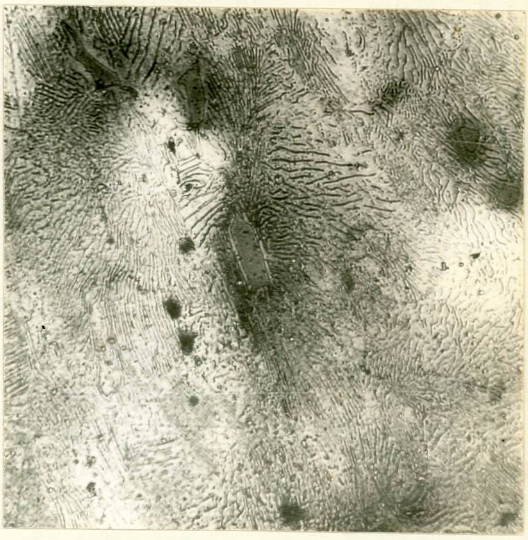
Figure 11.



X500, Murakami's etch.

White cast iron after heating 12 hours at 1700° F.

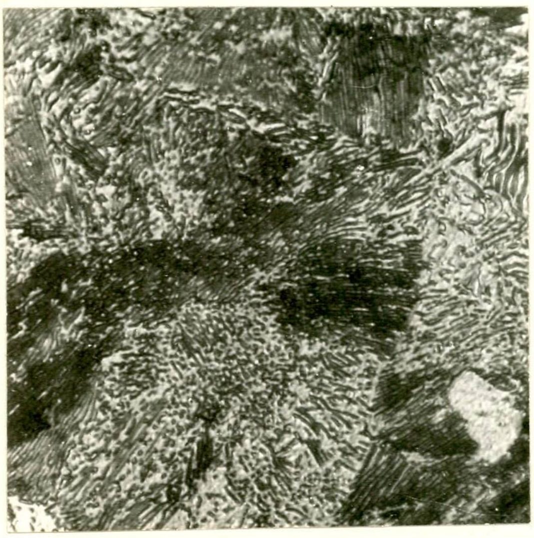
Figure 12.



X500, Murakami's etch.

White cast iron after heating 50 hours at 1700° F.

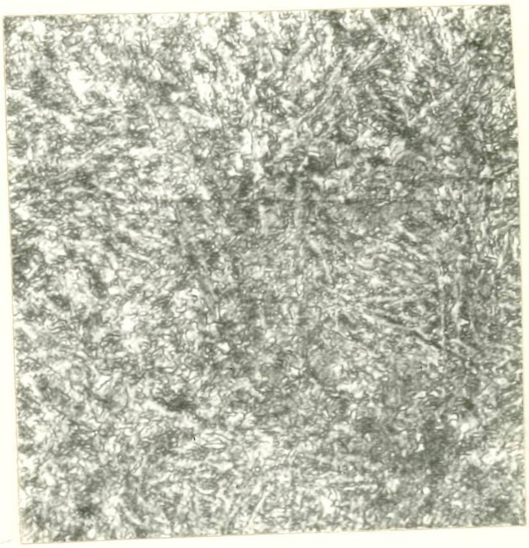
Figure 13.



X1500, nital etched.

Link cyanided at 1600° F. for 30 minutes. Air-cooled. Heated 2 minutes to 1400° F. Oil-quenched.

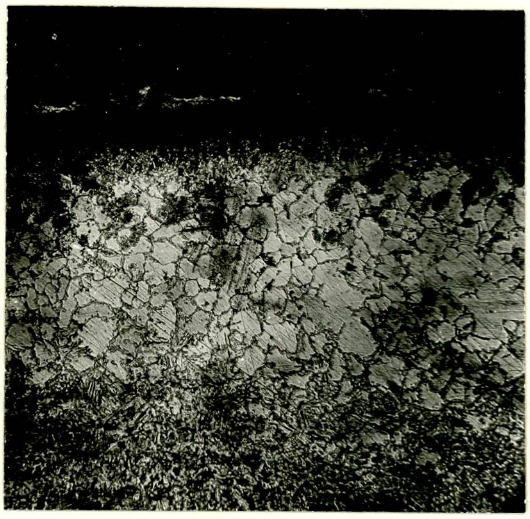
Figure 14.



X1500, nital etched.

Link cyanided at 1600° F. for 40 minutes. Oil-quenched. Heated 4 minutes to 1400° F. Oil-quenched.

Figure 15.



X100, nital etch.

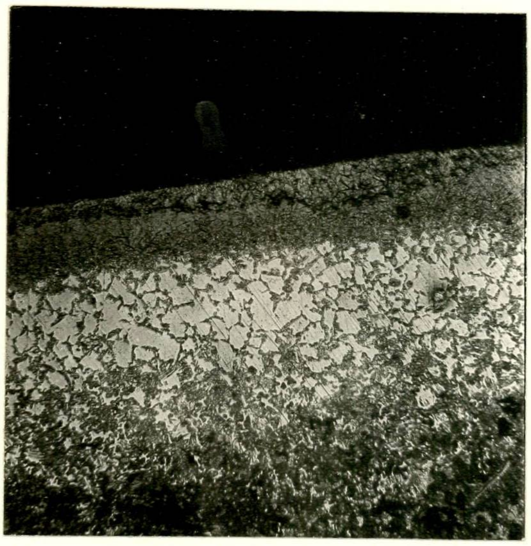
Case on link given a subcritical cyaniding treatment for 34 minutes and quenched from 1425° F. into oil.

Figure 16.

X100, nital etch.

Case on link cyanided 60 minutes at 1425° F. and austempered at 300° F. (Section of eye portion).

Figure 17.

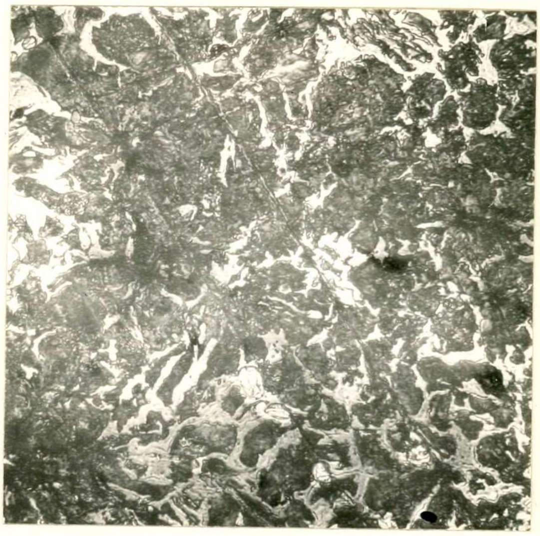


X100, nital etch.

Case on link cyanided 30 minutes at 1400° F. and austempered at 300° F. for 30 minutes.

(Section of eye portion).

Figure 18.

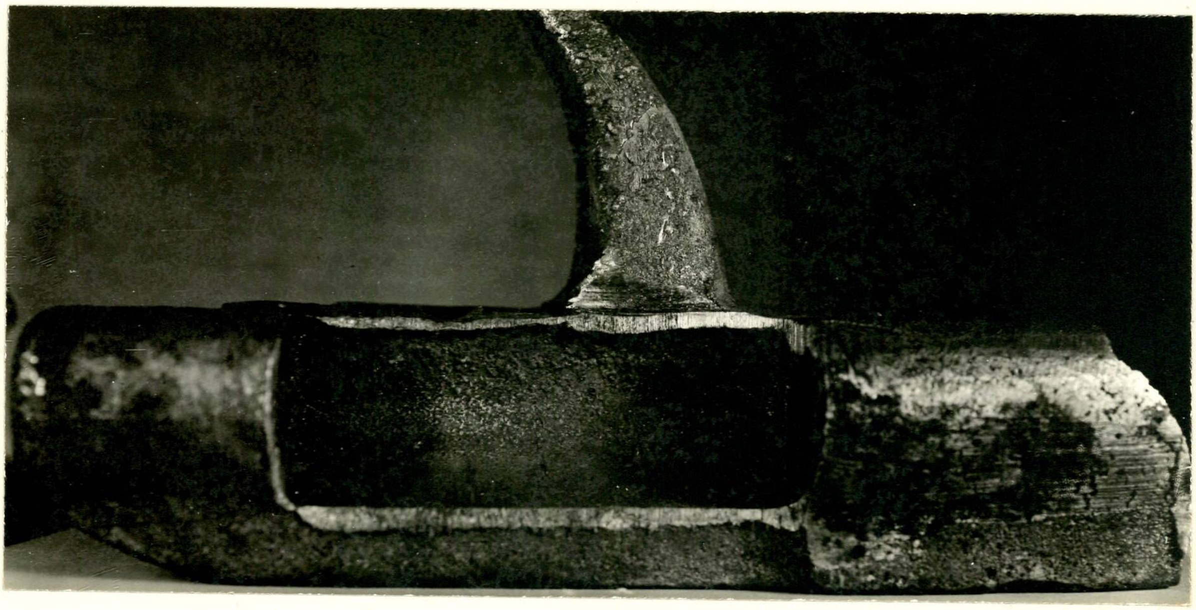


X500, nital etch.

Core of link cyanided 30 minutes at 1400° F. and austempered at 300° F. for 30 minutes.

(Section of eye portion).

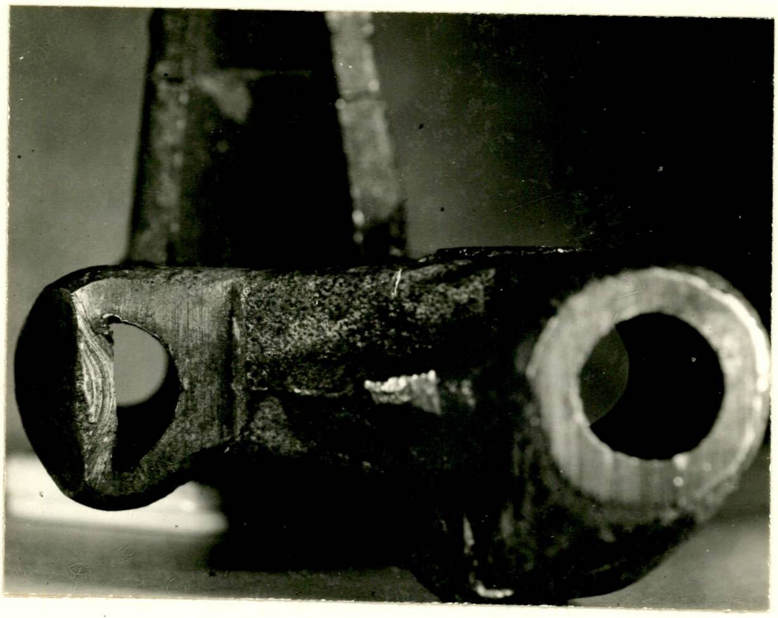
Figure 19.



Deformation obtained on guide portion of link austempered from 1400°-1450° F. in salt at 600° F. for 30 minutes.

(Natural size).

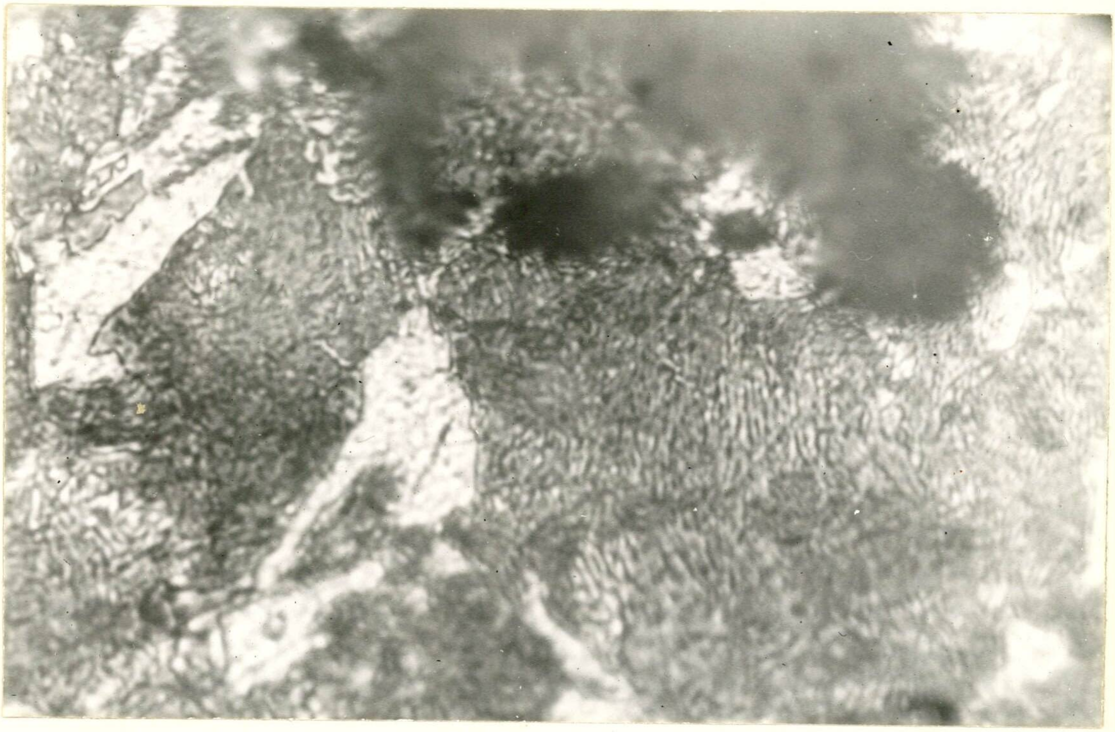
Figure 20.



Deformation obtained on eye portion
on same link as shown
in Figure 19.

Magnification: $1\frac{1}{2}$ times natural size.

Figure 21.



X3000, nital etch.

Section of eye portion of link austempered from 1400°-1450° F. into salt at 600° F. for 30 minutes.

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