File

O T T A W A September 20th, 1943.

R E P O R T

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1496.

Comparative Examination of Seven Types of Malleable Iron and Cast Steel Track Links for the Universal Carrier.

(Copy No. 32.)

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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Abstract

This report deals with the investigation of the properties of seven types of universal carrier track links. The bend, impact, and physical characteristics of blackheart, whiteheart and austempered malleable iron links are compared. Results are also given for the cast steel links, both with and without hardened eye-holes. Reference is made to field test performance of several types of these links.

Origin of Material and Object of Investigation:

The material for the investigation was submitted from time to time by Dr. C. W. Drury, Director of Metallurgy, Army Engineering Design Branch, Department of Munitions and Supply, Ottawa and Toronto, Ontario, and is covered by the following requisition orders:

Requisition No. 28, AEDB Lots Nos. 111-115 (Report No. 23, Section 5A); dated October 16th, 1942, at Ottawa.

Requisition No. 30, AEDB Lots Nos. 116-119 (Report No. 23, Section 5B); dated October 16th, 1942, at Ottawa.

Requisition No. 378, AEDB Lot No. 414 (Report No. 9B); dated February 9th, 1943, at Toronto.

The object of this investigation is to carry out a

(Origin of Material and Object of Investigation, cont'd) -

complete metallurgical examination and comparison of the properties of the different types of universal carrier track links produced since the beginning of the war.

Source of Supply:

Type of Track Link	Supplier
Whiteheart Malleable Iron -	Maddock Foundry, England.
Blackheart Malleable Iron -	International Harvester Co., Hamilton, Ontario.
Austempered Malleable Iron -	International Harvester castings, heat treated, O.D.M.L.
Cast Steel (1) -	Ford Motor Co. of Canada, Windsor, Ontario.
" " (2) -	Auto Specialties Mfg. Co., St. Joseph, Michigan.
" " (3) -	Campbell, Wyant & Cannon Foundry Co., Muskegon, Michigan.
" " (Hardened Eye-holes) -	Campbell, Wyant & Cannon Foundry Co., Muskegon, Michigan.

General Aspects of Material:

Universal carrier track links may be roughly classified as, (A) malleable iron links and (B) cast steel links.

A. Malleable Iron Links -

These are either whiteheart or blackheart. After malleabilizing they are case-hardened (shallow) to produce a surface which will resist wear.

British production links for the universal carrier are of whiteheart malleable. This type of track link is cast of white iron (high sulphur, low carbon and silicon) in sand. The castings are malleabilized, during which treatment much of the carbon is removed. The remaining part is mainly in the form of pearlite and temper carbon.

British specifications at the beginning of the war

(General Aspects of Material, cont'd) -

required that universal carrier track links be whiteheart malleable iron. This set specification, combined with insistence that it be adhered to, resulted in the production of blackheart malleable iron track links in Canada, since this was the closest available material to whiteheart and no Canadian manufacturer had ever produced the latter. Production was started and carried out as a result of considerable research done by these Laboratories in co-operation with the International Harvester Co. of Canada. A satisfactory cased blackheart malleable link was produced. This link differed from the whiteheart malleable link in that malleabilizing was carried out in an almost neutral rather than an oxidizing atmosphere. As a result, decarburizing only occurred in approximately the outer 0.010 inch, the remainder of the material being pearlite and temper carbon. This pearlite was left in the lamellar condition because in the hardening of the case the link was heated only for a period sufficient to bring the skin only over its critical. It might be mentioned that if 0.010-inch decarburization was not obtained, a brittle link was produced.

During further investigations at these Laboratories blackheart malleable links were given an austempering treatment to produce a track link which would be less liable to eye-hole stretch in service. Since the austempering treatment mainly affects the thin sections (eye-hole walls), better wearing properties also were expected of these links. Austempered track links are on field test at the present time, at Windsor, Ontario.

B. Cast Steel Links -

Steel links are all cast from metal conforming approximately to the chemical specifications of Ford No. 4 steel. These links are hardened and drawn. The cast steel

(General Aspects of Material, cont'd) -

link with hardened eye-holes is experimental. It is an attempt to produce a hardened eye-hole surface by using a core wash of carbonaceous material.

HEAT TREATMENT:

A. Malleable Iron Links.

Whiteheart Malleable -

The castings are malleabilized by heating in large furnaces, surrounded by a mixture of new and spent iron ore, for several days at a temperature of 950° to 1000° C. The links are then given a shallow case-hardening treatment. In this cyaniding treatment the casting is held at 1750° F. in 50 per cent cyanide for ½ hour, air cooled, reheated to 1475° F. in weak cyanide solution, and quenched in mineral oil.

Blackheart Malleable -

Annealed in regular blackheart cycle but with some iron ore in packing (iron ore added of high silicon type and in amounts just sufficient to make up for dust loss. The castings are preheated to approximately 1500° F., then heated in a cyanide salt bath at 1620° F. for 34 minutes, air cooled for 20 minutes, heated in hardening salt bath at 1450° F. for 2 minutes, and quenched in oil at 120° to 180° F.

Austempered Links -

Links which had been annealed in the regular blackheart cycle but not decarburized were cyanided at 1500° F. for 30 minutes, then quenched into caustic soda at 590° to 680° F. for 45 minutes.

B. Cast Steel Links.

Ford Motors -

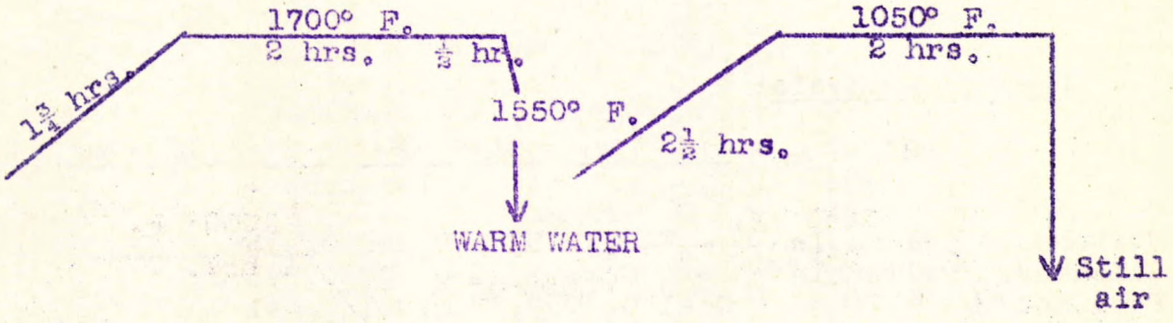
Castings held at 1500° F. for 1½ hours, quenched in caustic soda or water, then drawn at 1050° to 1100° F. for 2½

(General Aspects of Material, cont'd) -

hours to Brinell 286-302.

Auto Specialties -

Heated for 1½ hours to 1700° F., maintained at this temperature for 2 hours, cooled ½ hour to 1550° F., and quenched in warm water. The links are then drawn to Brinell 286-302 by treating as follows: Heated for 2½ hours to 1050° F., kept at this temperature for 2 hours, taken out, and allowed to cool in still air.



DIAGRAMMATIC SKETCH OF HEAT TREATMENT.

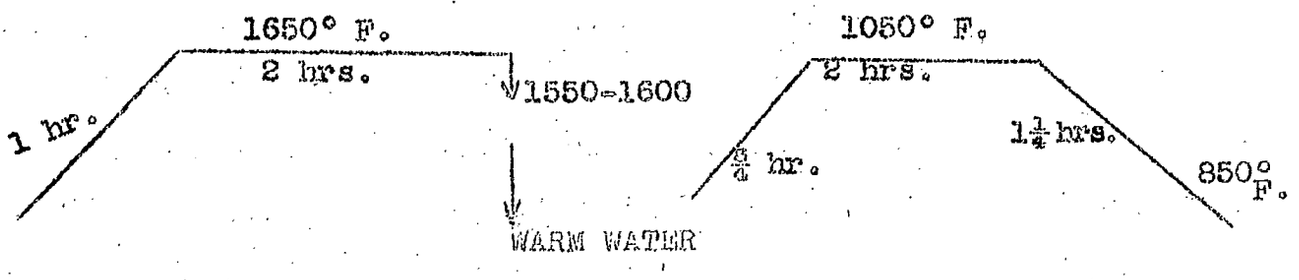
Campbell, Wyant and Cannon Foundry Co. -

Heated for 1 hour up to 1650° F., kept at this temperature for 2 hours, cooled to 1550-1600° F., and quenched in warm water; drawn at 1050° F., for 2 hours, cooled to 850-900° F., and removed from furnace.

The experimental track link with hardened eye-holes was produced in the following way: The pin cores were coated with a wash of carbonaceous material and dried for 15 minutes at 300° F. The moulds were then poured with regular Ford No. 4 steel. The castings were then heat-treated as explained above.

(Continued on next page)

(General Aspects of Material, cont'd) -



DIAGRAMMATIC SKETCH OF HEAT TREATMENT.

Chemical Analysis:

	C	Mn	Si	P	S	Cu	Mo	Ni	Cr
	- Per cent -								
Whiteheart Malleable	- *	0.28	0.43	0.056	0.205				
Blackheart Malleable	-	0.24	1.18	0.120	0.075	0.07			
Ford Motors	0.41	0.77	0.29	0.031	0.041	0.16			
Auto Specialties	0.41	0.78	0.40	0.027	0.026	0.06	0.18	0.04	0.02
C. W. & C.	0.36	0.78	0.45	0.045	0.041	0.53			

* It is not possible to get representative carbon determinations of malleable iron.

Macro-Examination:

Castings were free from surface defects. The track links were weighed, the average weight of four links being considered as representative of each type.

	Average Weight	
	Pounds	Ounces
Whiteheart Malleable Iron -	3	1
Blackheart Malleable Iron -	3	1
Austempered Malleable Iron -	3	1
Ford Motors, Cast Steel -	3	2
Auto Specialties, Cast Steel -	3	4
Campbell, Wyant and Cannon, Cast Steel -	2	15
C.W. & C. Hardened Eye-holes -	2	15

(Continued on next page)

(Macro-Examination, cont'd) -

Track links in the 'as cast' condition, showing position of gates and risers, are illustrated in Figures 1 to 4.

X-Ray Examination:

X-ray examinations were made at the National Research Laboratories, Ottawa. The examination revealed in all cases small shrinks in the middle eye-hole area, toward the grouser on the three-eye-hole side of the link. Other small shrinks were present.

Tensile Tests:

Four micro tensile specimens were cut from each type of cast steel link and the tensile properties determined. Micro tensile specimens are of no value for malleable iron. Specimens cast and malleabilized with the production links were not available.

AVERAGE VALUES FOR FOUR MICRO TENSILE SPECIMENS.

Type of Link	Tensile strength, p.s.i.	Yield point, p.s.i.	@Elongation, per cent	@Reduction in area, per cent
Ford Motor's	125,000	103,700	20	36
Auto Specialties	134,000	120,700	8	18
Campbell, Wyant and Cannon	119,100	107,400	10	24

@ Micro tensile specimens are not as accurate in elongation and in reduction in area as are standard specimens. Also, the uniformity of the casting at the point where the specimen was taken has a great influence on the results obtained.

Bend Tests:

Bend tests were made, using the Amsler Universal testing machine with a 1-inch radius block and 8-inch centres. The results were as follows:

(Continued on next page)

(Bend Tests, cont'd) -

Type of Link		Pounds	Angle
Whiteheart malleable iron	-	15,750	13°
		11,100	5°
		9,450	2.5°
		14,500	6.5°
		14,300	9.0°
		13,600	11.0°
Blackheart malleable iron	-	13,600	9°
		11,450	11°
Austempered malleable iron	-	15,800	2°
		14,700	3°
Ford Motor's cast steel	-	17,500	10°
		28,000	5°
Auto Specialties cast steel	-	20,200	20°
		21,400	11°
Campbell, Wyant and Cannon cast steel	-	21,500	14°
		20,500	15°
C.W. & C. cast steel, hardened eye-holes	-	18,700	11°
		20,000	7°

Drop Impact Tests:

Standard impact tests were made on both guide lugs and also on the barrels of all types of links. Illustrations of the impact testing apparatus used are shown in Figures 5 and 6. A 50-pound weight was dropped several times, from various heights, until failure occurred. In most cases the links fractured cleanly on failure. When this was not the case the test was continued to the point where the lugs were so badly bent that it was impracticable to proceed any further.

(Continued on next page)

(Drop Impact Tests, cont'd) -

Drop Impact Results.

Type of Link	Link No.	LUGS No. of Blows	LUGS Ft.-lb.	LUGS Result	BARREL No. of Blows	BARREL Ft.-lb.	BARREL Result
Whiteheart malleable iron	1	(a) 3	350	Failed	3	350	Failed
		(b) 1	350	"			
	2	(a) 3	350	"	3	400	"
		(b) 2	350	"			
	3	(a) 2	350	"	2	400	"
		(b) 2	350	"			
	4	(a) 4	350	"	3	400	"
		(b) 2	350	"			
Blackheart malleable iron	1	(a) 1	400	Unbroken	2	350	"
		(b) 2	400	Failed			
	2	(a) 2	400	"	3	350	"
		(b) 2	400	"			
Austempered malleable iron	1	(a) 1	300	"			
		(b) (1	350	"			
		(1	300	"	1	300	"
	2	(a) 2	300	"			
		(b) 2	300	"	4	250	
Ford Motor's cast steel	1	(a) 2	400	Failed	2	400	Failed
		(b) 1	400	"			
	2	(a) 1	350	"	2	400	"
		(b) 2	350	"			
Auto Specialties cast steel	1	(a) 4	400	Unbroken	2	400	Unbroken
		(b) 4	400	"			
	2	(a) 4	400	"	4	400	"
		(b) 4	400				
Campbell, Wyant and Cannon cast steel	1	(a) 3	350	"	2	400	Failed
		(b) 3	350	"			
	2	(a) 3	400	"	2	400	"
		(b) 2	400	"			
C.W. & C. cast steel, with hardened eye-holes	1	(a) 3	350	"			
		(b) 3	400	"	4	400	Unbroken
	2	(a) 2	400	Failed			
		(b) 4	400	"	4	400	"

Hammer Tests:

Five links of each type were subjected to the standard hammer test. A link is considered to have sufficient ductility and toughness when the eye-holes will withstand the

(Drop Impact Tests, cont'd) -

blows of a hammer until they are two-thirds of their original diameter without cracking.

All links, with the exception of one whiteheart malleable link, passed this test.

Hardness Surveys:

Transverse sections were cut from the centre eye-hole on the three-eye side of the links. Hardness surveys were made across the grouser, toward the eye-hole surface. The Vickers hardness testing machine was used. A 1-kilogram weight was used for readings at the surface. All other readings were made with the 10-kilogram weight.

Type of Link	VICKERS HARDNESS NUMBERS											
	Sur-	Distance from Eye-hole Surface, in Inches										
	face	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.15	0.20
Whiteheart malleable	365	73	86	100	100	118	136	134	134	132	132	125	125
Blackheart malleable	235	212	185	170	156	156	156	172	185	188	192	198	198
Austempered malleable	294	150	180	210	242	235	228	234	240	245	250	240	242
Ford's	299	294	274	268	265	270	275	272	270	268	266	256	254
Auto Specialties	223	240	258	262	270	265	260	260	262	264	264	268	264
C.W. &C.	285	225	266	264	264	262	260	260	262	245	250	248	245
C.W. &C. hardened eye-holes	390	314	314	310	309	300	299	298	298	295	294	288	294

Microscopic Examination:

Transverse sections were cut from a link of each type and microscopic examinations of these were made.

A. - Malleable Iron Links.

Whiteheart Malleable. - These specimens had inclusions visible in both the etched and unetched conditions. Figures 7 and 8 illustrate metal structure in thin (eye-hole) section and at surface of eye-hole respectively. Specimens etched with 2 per cent nital, magnification X200.

Blackheart Malleable. - Figures 9 and 10, on Page 23, are photomicrographs, at X200 magnification, taken at thin (eye-hole) section and at eye-hole surface. The specimens were etched with 2 per cent nital.

Austempered Malleable. - The metal structure in the eye-hole area is shown on Page 23 by Figures 11 and 12, photomicrographs at X1000 and X500 magnification respectively. Figure 13 (X200) illustrates the cyanide case at surface. All samples were etched with 2 per cent nital.

B. - Cast Steel Links.

Microspecimens of all types of cast steel links, in the unetched condition, indicated that the metal was clean and free from inclusions and that the structure was uniform across the section.

The photomicrographs listed below appear on Pages 24 to 25 herein. All samples were etched with 2 per cent nital.

Figure 14. - Structure of Ford track link, X250.

Figure 15. - Decarburized area at eye-hole surface of Ford link, X100.

Figure 16. - Structure of Auto Specialties link, X500.

Figures 17 and 18. - Illustrate metal structure of Campbell, Wyant and Cannon cast steel link before and after, respectively, a change in their heat

(Microscopic Examination, cont'd) -

treating technique. Both at X250.

Figure 19. - Decarburized area of C.W. & C. cast steel link.

Figure 20. - Shows photomicrograph taken at eye-hole surface of experimental link with hardened eye-holes, X250, etched with 2 per cent nital.

DISCUSSION:

With regard to physical appearance, freedom from surface defects, and weight of track link, all types are similar. X-ray examination would indicate that small shrinkage cavities in the middle eye-hole wall on the three-eye-side are characteristic of all universal carrier track link castings, both malleable and cast steel. These shrinks are toward the thick (grouser) part of the link and do not appear to be unduly serious.

The chemical composition of both blackheart and whiteheart links is consistent with that required to produce suitable malleable iron of each type. It has already been established that Ford No. 4 steel, properly heat treated, has best resistance to impact and abrasion over the track life period. There were only two variations from this chemical specification, namely, (1) 0.53 per cent copper in one type, which might slightly improve corrosion-resisting properties and affect the hardenability; (2) 0.18 per cent molybdenum, which would help hardenability and aid in preventing temper brittleness if the steel is subject to this characteristic.

Tensile properties are as expected for this type of steel and the heat treatment used.

Reduction in area and elongation, as measured on micro tensile specimen, should not be considered to be as

(Discussion, cont'd) -

accurate as those taken on the standard size specimen. Microspecimens are used in the absence of test coupons and also in order to determine the properties of the metal in the actual casting; it must be remembered, however, that uniformity of casting determines the degree to which the results are representative.

Bend and impact requirements for universal carrier malleable iron track links which were adopted by the manufacturers as a guide to their production were:

1. Links must withstand a bending load of 10,000 pounds without breaking, supported by 8-inch centres. The angle of bend after breaking and passing 10,000 pounds must exceed 5 degrees.

2. Both the lugs and the barrel of the link must withstand an impact blow of 112 foot-pounds.

Results as obtained in this investigation show that both the whiteheart and the blackheart malleable track links have marginal bend properties. The austempered type will withstand the required load without breaking but has not the same ductility as the others.

Cast steel links pass these specifications by a wide margin and are definitely superior to malleable iron in this respect.

Impact properties of malleable iron and Ford track links are all of the same order and are well above the present requirements. The remaining types of cast steel material have even better impact properties; when subject to impact these links bent rather than broke, indicating greater ductility and better resistance to shock.

It should be pointed out, however, that the results obtained in field tests indicate that great ductility may be unnecessary; it leads to eye-hole stretch. Reasonable resistance to shock, as was required under the 112-foot-pound impact

(Discussion, cont'd) -

specification, is sufficient to ensure satisfactory service.

Specifications with regard to the hardness values of malleable iron links require that they should not exceed 200 V.P.N. in the eye-hole area, but 350 V.P.N. is allowed in the barrel. Blackheart and whiteheart malleable iron conform to this specification. The austempered link, of course, is higher in the core.

The transverse hardness gradients from the grouser to the eye-hole surfaces show the characteristic differences between the two methods of malleabilizing. The British link has a very thin case, 0.003 to 0.005 inch. The metal backing this case is very soft (73.6-134 V.P.N.). This soft, low-carbon area would be subject to stretch during service and, also, to heavy wear once the case had worn away. Opposed to this, hardness values for blackheart malleable track links indicate a very small area of low-carbon metal backing the shallow case. The hardness of austempered links is higher at the surface as well as towards the thicker sections. This, of course, would decrease both wear and stretch of the links.

Hardness readings for cast steel links vary between 250 and 285 V.P.N., 10-kilogram load. The low hardness at the eye-hole surface of the Auto Specialties link is probably due to slight decarburization.

Gradually increasing hardness towards the eye-hole surface of the C. W. & C. experimental link is interesting, and indicates an area of gradually increasing carbon content rather than a case effect. This link should give good service. It is understood that blowholes are caused by the carbonaceous core wash. Experimental work should be carried out to eliminate

(Discussion, cont'd) -

this difficulty, as this link shows distinct promise.

Microscopic examination of links in Group A show that all have the normal high-carbon cyanide martensitic case (see Figures 8, 10, and 13).

The metal structure in the core of the eye-hole area is, for all links, composed of temper carbon and ferrite in a matrix of pearlite (See Figures 7, 9, 11, and 12). Small particles of cementite are imbedded in the matrix of the blackheart type, indicating that it has not been sufficiently annealed.

The pearlite in the austempered link is much finer than that of the other two, a result of the austempering treatment. It should be noted here that although a salt quench has been used bainite has not been formed. The fine pearlite structure obtained results in higher hardness, as already noted. Results of field tests now in progress would indicate that the anticipated toughness and resistance to stretch have also been obtained.

The amount of ferrite varies from small particles in the thicker sections to almost complete decarburization in the thin sections of some links.

Excessive decarburization is not characteristic of any one type but appears to be frequent in all.

For austempering, the links should not be decarburized, as this defeats the purpose of the treatment, namely, higher hardness with the retention of sufficient ductility for service.

The metal structure of all track links in Group B is tempered martensite with some slight decarburization (0.003-0.005 inch) at the eye-hole surfaces (see Figures

(Discussion, cont'd) -

14 to 19).

The structure of the Campbell, Wyant and Cannon track link as received at these Laboratories is shown in Figure 17. The matrix is martensitic but ferrite had been precipitated at the grain boundaries. This was caused by cooling to below the critical temperature prior to quenching. This link was re-heat-treated and the normal tempered martensite structure was obtained. It is reported that during the heat-treating cycle at the Campbell, Wyant and Cannon plant, the castings passed through a low-temperature zone in the furnace before quenching; this would have accounted for the undesirable metal structure. This condition was immediately corrected.

A photomicrograph (Figure 20) taken at the eye-hole surface of the link with hardened eye-holes shows a very similar structure to that in the thicker sections. The hardness values of this outer zone, however, indicate a higher carbon content.

Conclusions:

1. Shrinkage cavities in the middle eye-hole wall on the three-eye-side are characteristic of universal carrier track link castings, both malleable and steel.

2. The chemical composition of all of the cast steel track links conforms very closely to the specifications of Ford No. 4 steel.

3. Whiteheart and blackheart malleable iron track links have very similar bend and impact properties. Austempered malleable links have lower impact properties, will withstand in excess of the required bending load, but break at an angle

(Conclusions, cont'd) -

less than the required 5 degrees.

4. Bend and impact properties of cast steel track links are superior to those of malleable iron links.

5. All types of track links possess sufficient ductility as measured by the standard hammer test.

6. Excessively decarburized areas in the thin sections of malleable iron links decrease strength and result in stretch during service. The small decarburized areas in cast steel links are not considered serious defects.

7. Hardness range for cast steel links is 250 to 285 V.P.N.

8. The cast steel links were properly heat-treated to give optimum physical properties.

9. The experimental steel links have higher eye-hole surface hardness, which will give increased wear resistance.

GENERAL CONCLUSIONS:

It is felt that the cast steel link is the best universal carrier track link at the present time, since the excellent laboratory results are substantiated in field tests. This link could be further improved by hardening the eye-holes either (a) chemically, or (b) by some induction heating method. The carbonaceous core wash which was used to harden the eye-holes of the experimental links tested in this report gave encouraging results. It is known, however, that blow-holes occurred in the production of some of these shoes. Work should be carried out to see whether this difficulty can be overcome.

The blackheart malleable link which was produced

(General Conclusions, cont'd) -

in Canada gave reasonably good results but was not up to the standard of the steel links.

Austempered malleable links, which are now undergoing field tests, when last reported gave definite indications of being superior to the other types of malleable link, having given 3,500 miles with only two failures. Metallurgical examination of these two failures[©] showed excessive decarburization in one link and a casting defect in the other.

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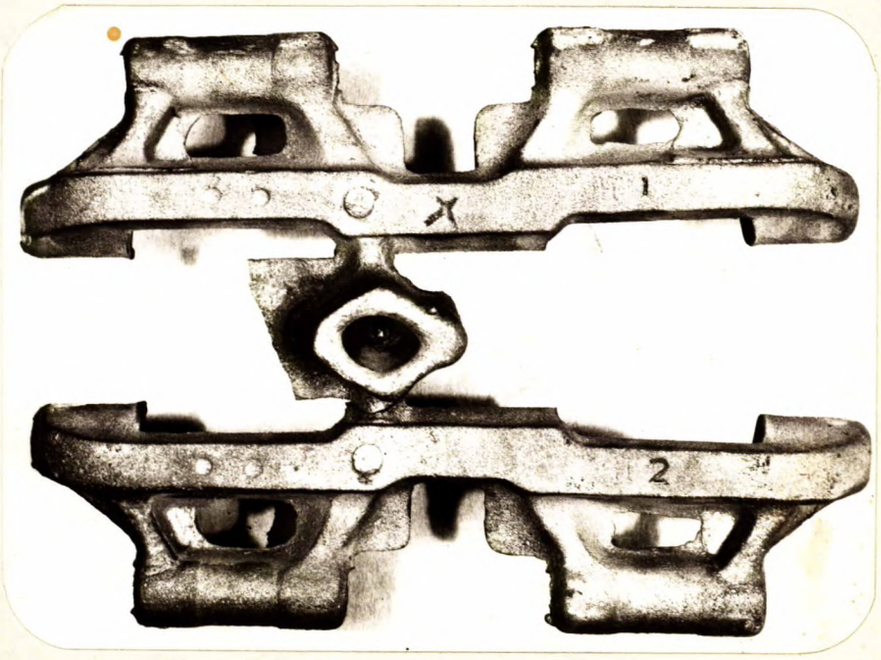
THM:SLG:GHB.

[©] O.D.M.L. Report of Investigation No. 1490, Sept. 2nd, 1943.

Figure 1.



INTERNATIONAL HARVESTER IRON CASTING.

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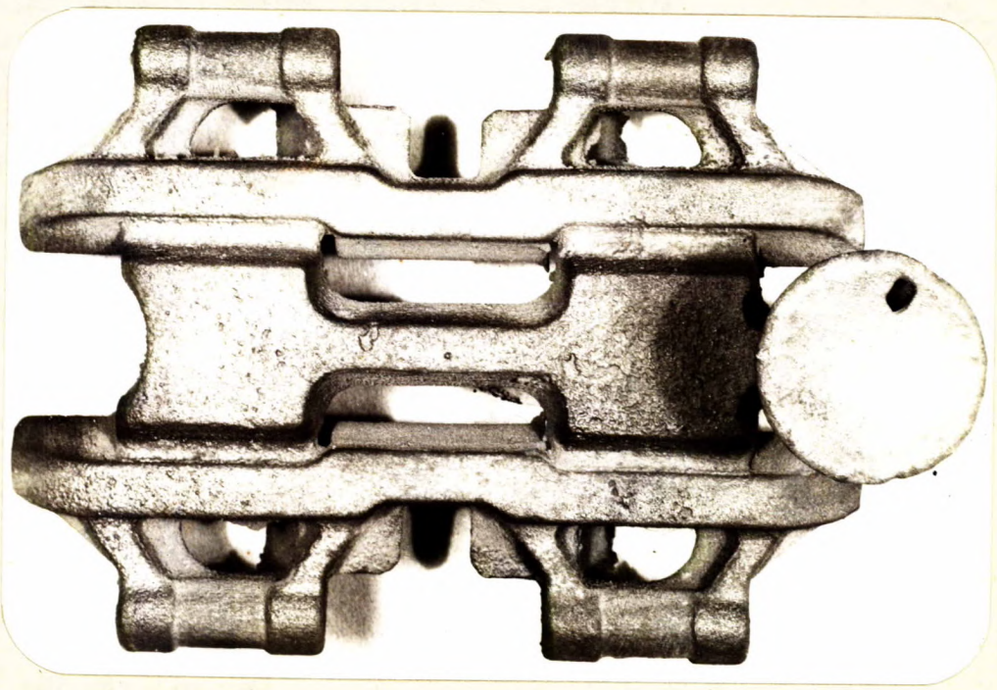
Figure 2.



FORD STEEL CASTING.

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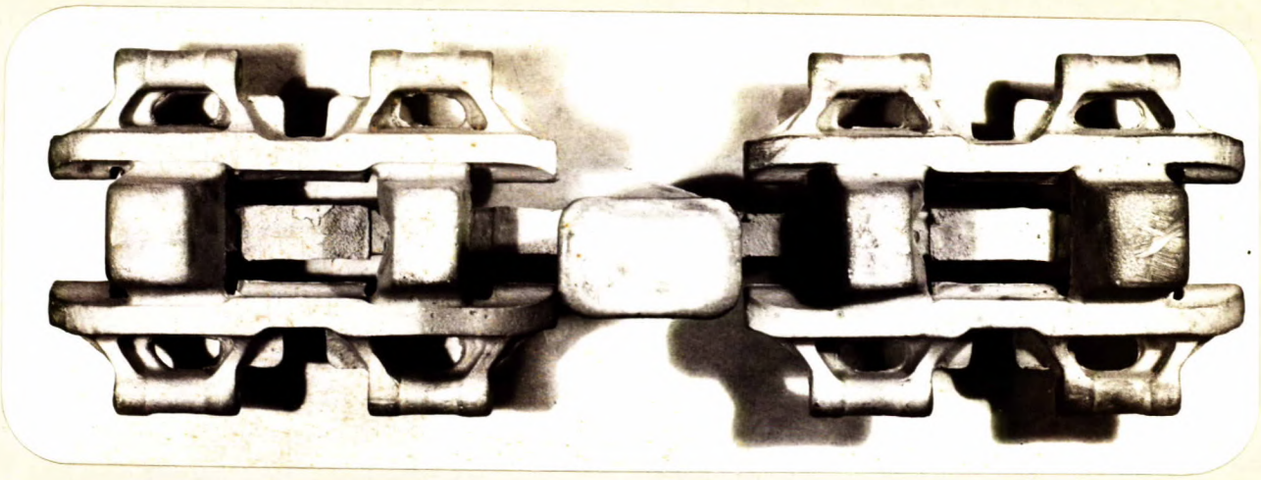
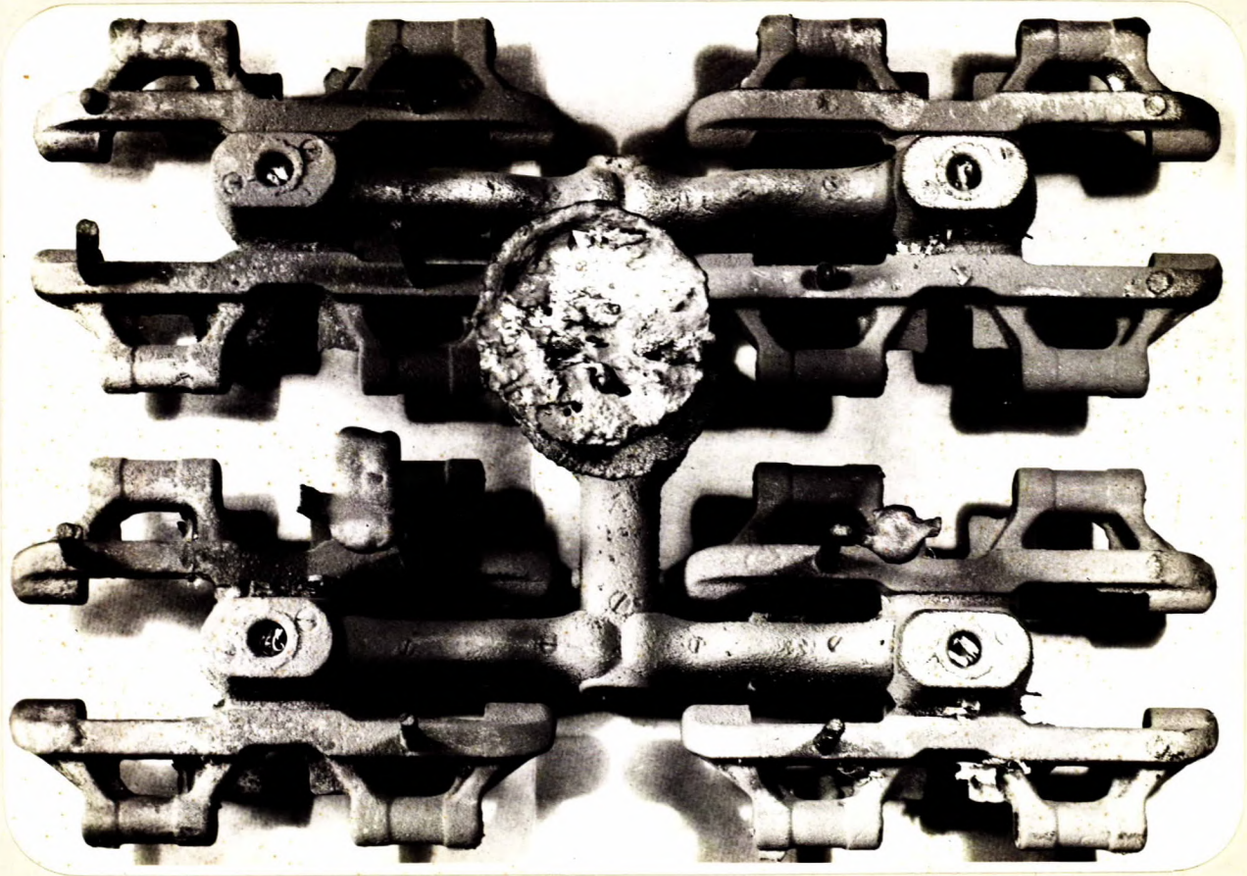
Figure 3.



CAMPBELL, WYANT AND CANNON STEEL CASTING.

Figure 4.



AUTO SPECIALTIES STEEL CASTING.

Figure 5.

IMPACT MACHINE.

Figure 6.

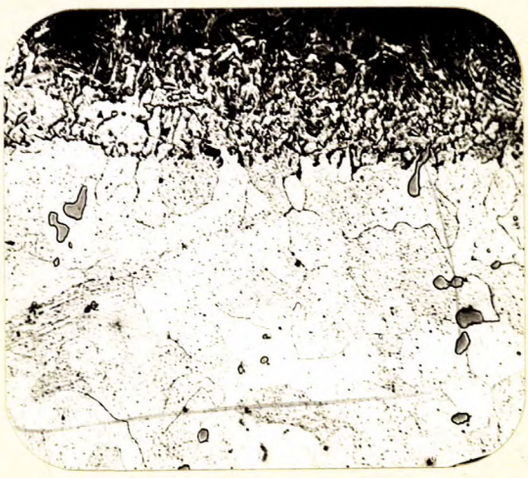
IMPACT MACHINE -- FIFTY-POUND WEIGHT FALLING ON LUG.

Figure 7.

X200, etched with 2 per cent nital.

WHITEHEART MALLEABLE, CORE STRUCTURE.

Figure 8.



X200, etched with 2 per cent nital.

WHITEHEART MALLEABLE, CYANIDE CASE.

Figure 9.

X200, nital etch.

BLACKHEART MALLEABLE,
CORE STRUCTURE.

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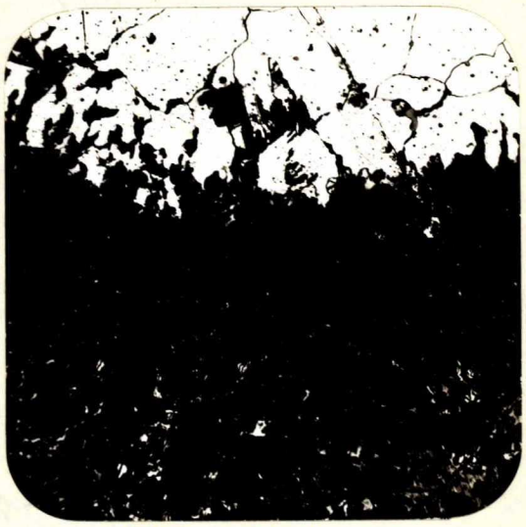
Figure 10.



X200, nital etch.

BLACKHEART MALLEABLE,
CYANIDE CASE.

—

Figure 11.

X1000, nital etch.

AUSTEMPERED MALLEABLE,
CORE STRUCTURE.

—

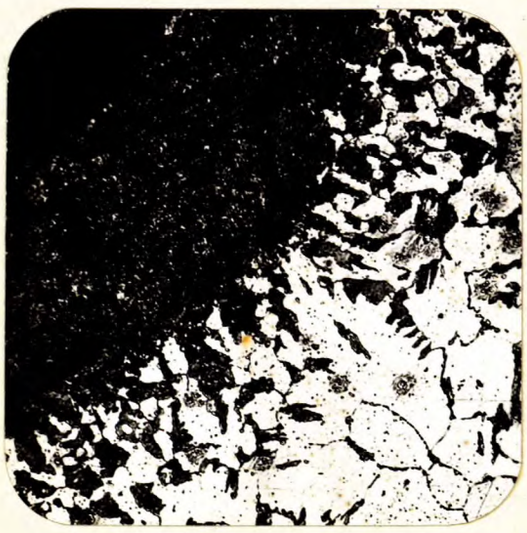
Figure 12.

X500, nital etch.

AUSTEMPERED MALLEABLE,
CORE STRUCTURE.

—

Figure 13.



X200, nital etch.

AUSTEMPERED LINK,
CYANIDE CASE.

—

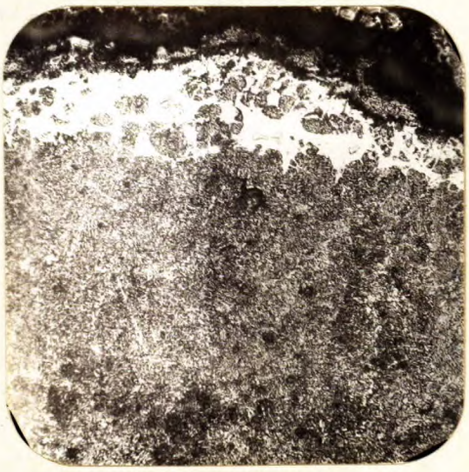
Figure 14.

X250, nital etch.

FORD CAST STEEL,
QUENCHED AND DRAWN.

—

Figure 15.

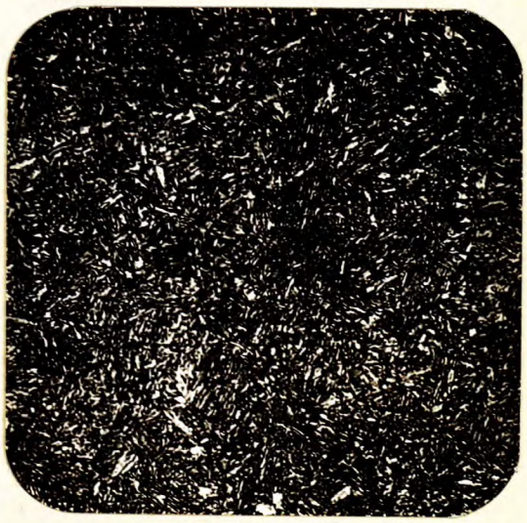


X100, nital etch.

FORD CAST STEEL, SHOWING
DECARBURIZATION AT SURFACE.

—

Figure 16.

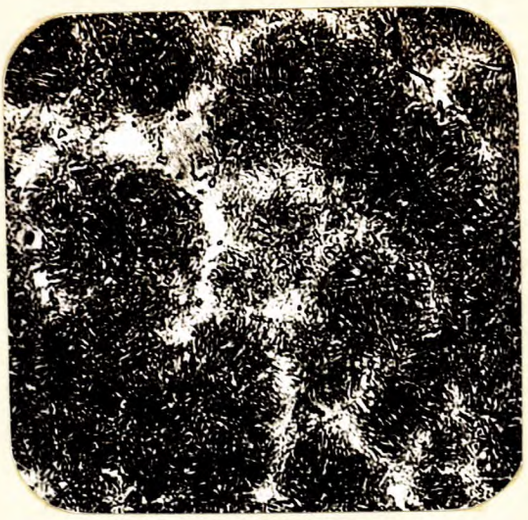


X500, nital etch.

AUTO SPECIALTIES
CAST STEEL.

—

Figure 17.

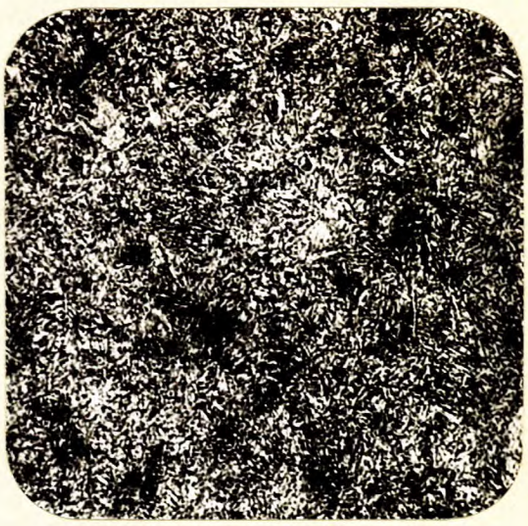


X250, nital etch.

CAMPBELL, WYANT & CANNON CAST STEEL.

—

Figure 18.



X250, nital etch.

CAMPBELL, WYANT & CANNON REHEAT-TREATED LINK.

—

Figure 19.

X100, nital etch.

DECARBURIZED AREA AT EYE-HOLE SURFACE OF C.W. & C. LINK.

—

Figure 20.

X250, nital etch.

EYE-HOLE SURFACE OF EXPERIMENTAL LINK WITH HARDENED EYE-HOLES.

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IHM:SIG:GHB.