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OTTAWA October 26, 1945.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1949.

Metallurgical Examination of Cracked Flame-Hardened Rail Segments from a Revolver Gantry Crane.

(Copy No. 10.)

Bureau of Mines
Division of Metallic
Minerals
-
Physical Metallurgy
Research Laboratories

CANADA
DEPARTMENT
OF
MINES AND RESOURCES
Mines and Geology Branch

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Origin of Material and Object of Investigation:

On September 14, 1945, two rail segments (see Figure 1) from a Revolver Gantry Crane, H. M. C. Dockyard, Shelburne, Nova Scotia, were submitted by the Director of Scientific Research and Development, Department of National Defence, Naval Service, Ottawa, Ontario, under Requisition No. 62, File No. NS 9310-112/10, Vol. 1.

This requisition, dated September 7, 1945, requested a metallurgical examination in order to determine the cause of the longitudinal cracks evident on the surface of the rail

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

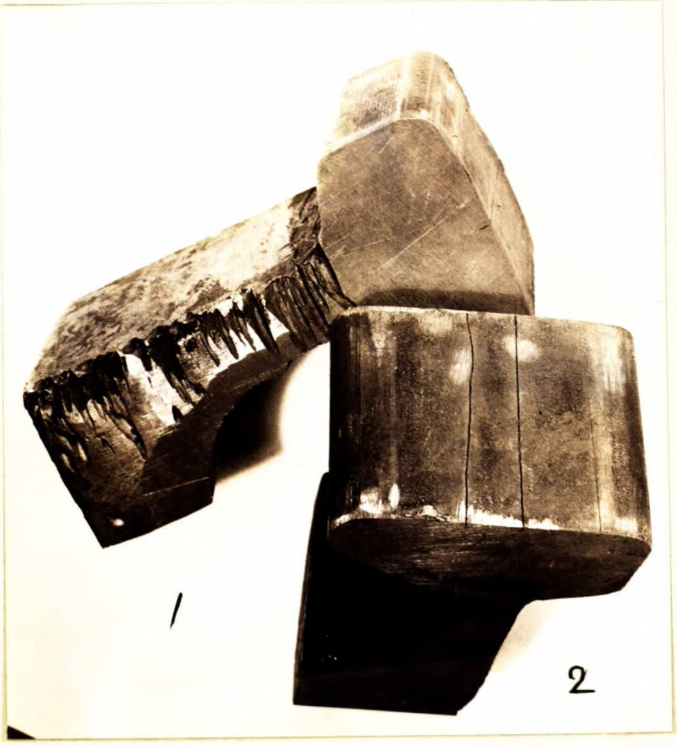
segments submitted.

The following information was supplied on the requisition and by a letter dated September 13, 1945, File No. N.S. 9310-112/10 (Staff):

> "The crane has been approximately 2 years in service.
>
> When the crane is operating at its maximum capacity (45 tons), a total weight of 264,000 pounds is bearing down on 10 affected rollers.
>
> There is a total of 30 rollers riding on the bull gear ring but only 10 rollers take the maximum weight at one time."

For purposes of identification the segments submitted will be designated Nos. 1 and 2, as shown in Figure 1.

Figure 1.



LONGITUDINAL CRACKS IN RAIL
SEGMENTS FROM REVOLVER GANTRY CRANE.

(Approximately ½ actual size).

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PROCEDURE:

1. Macro-Examination

Transverse sections were cut from each of the submitted rail segments, polished, and etched in 2 per cent nital. A photograph of the etched sections is shown in Figure 2. The extent and depth of the flame-hardened zones are clearly evident.

2. Chemical Examination.

Chemical analyses were made on samples taken from each of the rail segments submitted. The results are given in the following table:

TABLE I. - Chemical Analysis.

		Sample No. 1.	Sample No. 2.
		- Per	Cent -
Carbon	-	0.37	0.44
Manganese	-	0.57	0.94
Silicon	-	0.72	0.34
Sulphur	-	0.027	0.028
Phosphorus	-	0.023	0.027
Nickel	-	Nil.	Nil.
Chromium	-	0.06	0.02
Molybdenum	-	0.01	0.01

3. Hardness Tests.

Hardness readings were made on the two samples submitted, using the Vickers hardness tester and a 30-kilogram load. The results are as follows:

TABLE II.

	HARDNESS.	
Hardened Area	Vickers	Rockwell "C"(converted)
Sample No. 1.	370-409	38-42
Sample No. 2.	406-427	41-43

4. Mechanical Tests.

A 0.505-inch-diameter tensile test piece and a standard Izod test piece were machined from Sample No. 2. The

(Procedure, cont'd) -

results are as follows:

TABLE III.

*Ultimate stress, p.s.i.	83,700
Yield stress, p.s.i.	48,000
Elongation, per cent in 2 inches	10
Reduction in area, per cent	15
Izod impact	11

* Fractured test piece exhibited flaw in metal.

5. Microscopic Examination:

Figure 3, taken at X11½ magnification, shows the extent of one of the cracks in the flame-hardened zone, in Sample No. 2.

Figure 4, taken at X100 magnification, shows the base of one of the cracks found in Sample No. 1. The segregation of the hardened metal is clearly visible.

Figure 5 illustrates the magnitude of some of the porosity noted in the steel. The photograph was taken at X100 magnification.

Figures 6 and 7, taken at X500 magnification, show the annealed structure of Samples Nos. 1 and 2 respectively in the areas unaffected by the flame hardening.

Figure 8 (at X1000 magnification) shows the martensitic structure of the rail, resulting from the flame-hardening operation.

Figure 9, taken at X500 magnification, shows a portion of the rail improperly hardened, as evidenced by the free ferrite present.

Figure 10 (at X500 magnification) shows segregation resulting during the cooling from the molten state, and unaltered by the subsequent annealing operation.

Discussion:

The chemical examination indicates that the rails were cast from medium carbon steel. Some residual alloying elements, with no important significance, are also present.

The microstructure indicates that the rails had been cast and subsequently annealed by slow cooling in the furnace (see Figures 6, 7 and 10). The surfaces of the rails were then hardened by means of the flame-hardening operation, the depth of penetration extending approximately 3/16 inch (see Figures 2 and 8).

The cracks were longitudinal in character and penetrated into the flame-hardened zone to a depth of 1/8 inch (see Figure 3). No evidence of penetration beyond the hardened zone was found.

The microstructure indicated a very considerable segregation in the steels (see Figure 10). During the casting operation, ferrite was precipitated about the manganese sulphide inclusions. Evidence of this segregation was noted in the hardened areas (see Figure 4).

Porosity in the metal, caused by improper casting procedure, was noted (see Figure 5). While the porosity observed is not considered abnormal for a cast steel, nevertheless this condition should be kept to a minimum for proper flame hardening.

It should be noted that by far the most common reason for cracking in flame-hardened steels is improper flame-hardening technique. Overheating followed by severe quenching will invariably result in cracking. The presence of free ferrite in the hardened zone (see Figure 9) is an indication of non-uniformity in the quenching operation.

The appearance of the cracks in the rail segments examined is typical of that resulting during the flame-hardening process. The complete absence of decarburization proves

(Discussion, cont'd) -

that the cracks did not occur during the heat-treating operation previous to flame hardening. It is thought that small cracks had been initiated during flame hardening and had subsequently opened up in service.

Another factor which may have contributed to the cracking is the marked segregation in the steel. This segregation would result in areas of high carbon adjacent to areas of low carbon, each having a different hardenability. A possible remedy for this would be a thorough soaking of the rail, by means of the torch, previous to quenching.

The following are some of the more important precautions which must be observed in order to prevent cracking during flame hardening:

1. The correct distance between the burner and the work must be maintained. Too close a proximity of the flame to the work may cause overhardening, surface cracks, and grain coarsening.

2. The correct water pressure must be determined. Lowering the water pressure may often eliminate the trouble.

3. The steels should be as free from abnormality as possible. The surfaces should be free from decarburization, seams, cracks and other imperfections, and wherever possible should be in a uniform annealed condition.

4. It is important that stress relieving be carried out as soon as possible after every flame-hardening operation, in order to prevent cracking. Local heating and the consequent local changes of structure, combined with extreme rapidity of quenching, set up abnormal structural stresses, which, when they exceed the ultimate strength of the steel, cause cracking and rupture.

Conclusions:

1. The results of the investigations show that the rails had been cast from medium carbon steel and subsequently annealed (see Figures 6, 7 and 10). The rail surface was hardened by means of the flame-hardening operation (see Figures 2 and 8).

2. Cracking was probably initiated during flame hardening due to faulty technique, and had subsequently opened up in service.

3. Contributing factors which resulted in failure may have been (a) segregation in the steel, and (b) porosity caused by faulty casting technique.

Recommendations:

If similar failures are current it is recommended that a thorough investigation be made into the flame-hardening technique, with special emphasis placed on the following:

(a) Distance between burner and rail surface.

(b) Uniformity of heating.

(c) Severity and uniformity of quench. (Correct water pressure).

(d) Proper surface conditions.

(e) Stress relief.

REFERENCES

1. The Flame Hardening Process -

MACHINERY, Vol. 62, No. 1591, April 8, 1943.

2. Selective Hardening with the Oxyacetyline Flame - R. I. Rolf.

TRANSACTIONS A.S.M., March 1939, Vol. 27, No. 1.

3. Some Needed Precautions When Induction and Flame Hardening - J. O. Almen.

METALS PROGRESS, December 1944.

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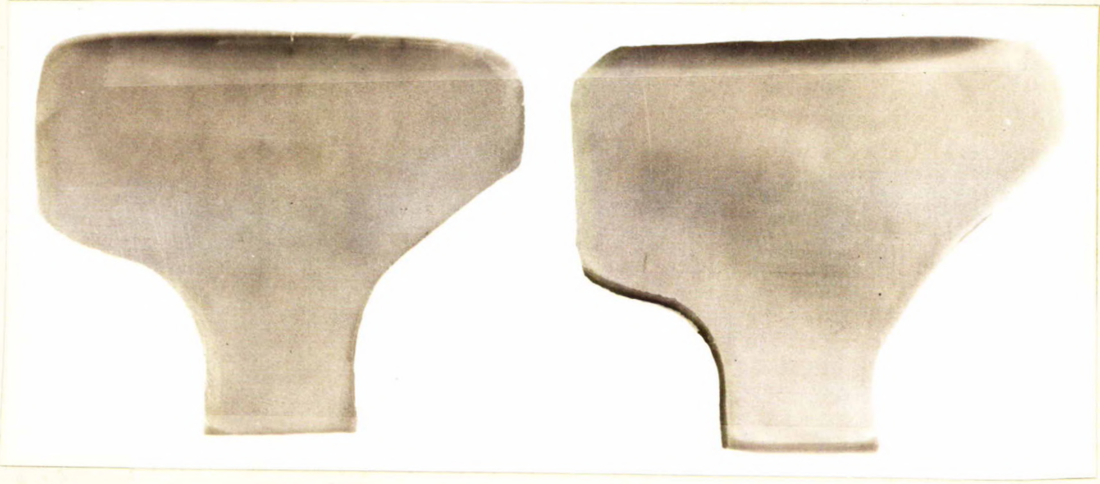
Figure 2.



Etchant, 2 per cent nital.

TRANSVERSE SECTIONS OF RAIL SEGMENTS, REVEALING EXTENT AND DEPTH OF FLAME-HARDENED AREAS.

(Actual size).

Figure 3.

X11½, unetched.

SHOWING DEPTH OF CRACK IN FLAME-HARDENED ZONE.

Sample No. 2.

Figure 4.

X100, nital etch.

SHOWING BASE OF CRACK IN HARDENED AREA OF SAMPLE NO. 1.

Note segregation.

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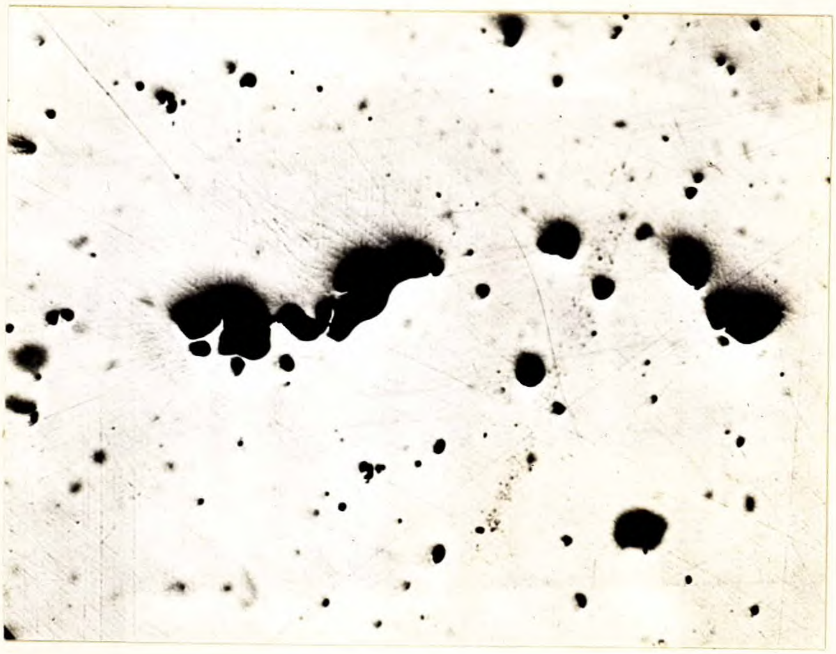
Figure 5.



X100, unetched.

SHOWING POROSITY IN STEEL, CAUSED BY FAULTY CASTING PROCEDURE.

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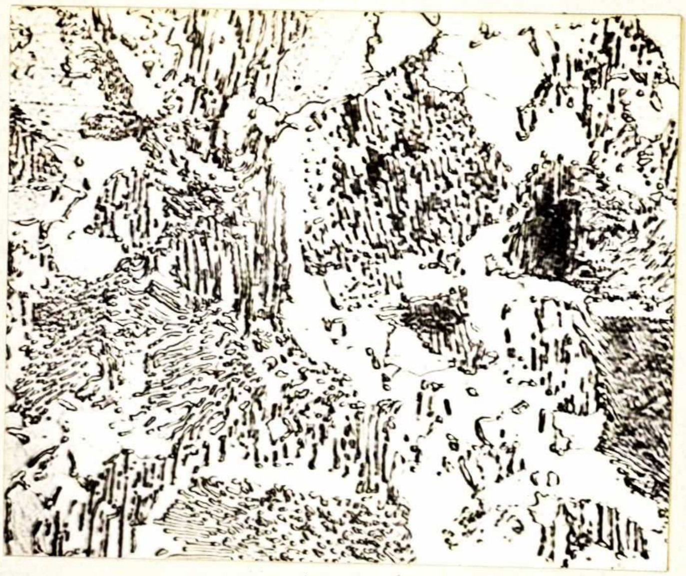
Figure 6.

X500, nital etch.

Sample No. 1.

-

Figure 7.



X500, nital etch.

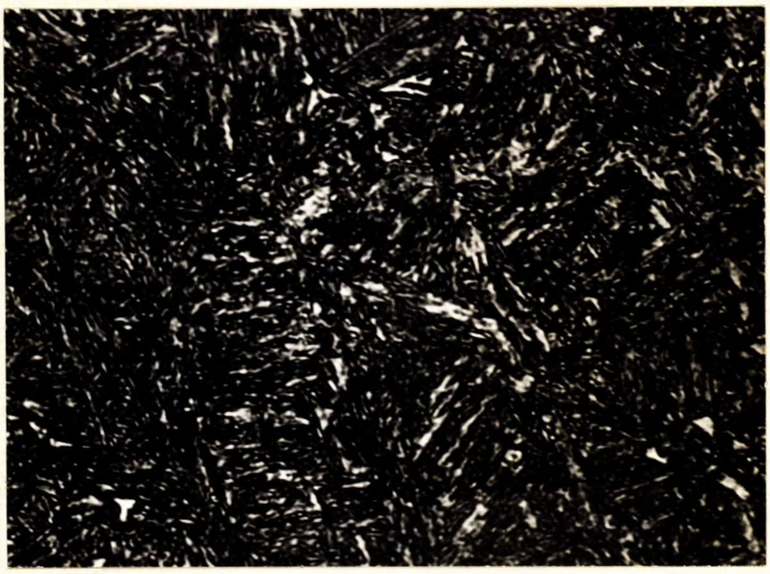
Sample No. 2.

-

MICROSTRUCTURE OF RAIL SEGMENTS IN AREAS UNAFFECTED BY THE FLAME HARDENING.

Well laminated pearlite indicates slow cooling in furnace.

Figure 8.



X1000, nital etch.

FLAME-HARDENED AREA, SHOWING MARTENSITIC STRUCTURE.

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Figure 9.

X500, nital etch.

FLAME-HARDENED AREA, SHOWING PROEUTECTOID FERRITE (WHITE) CAUSED BY IMPROPER COOLING RATE.

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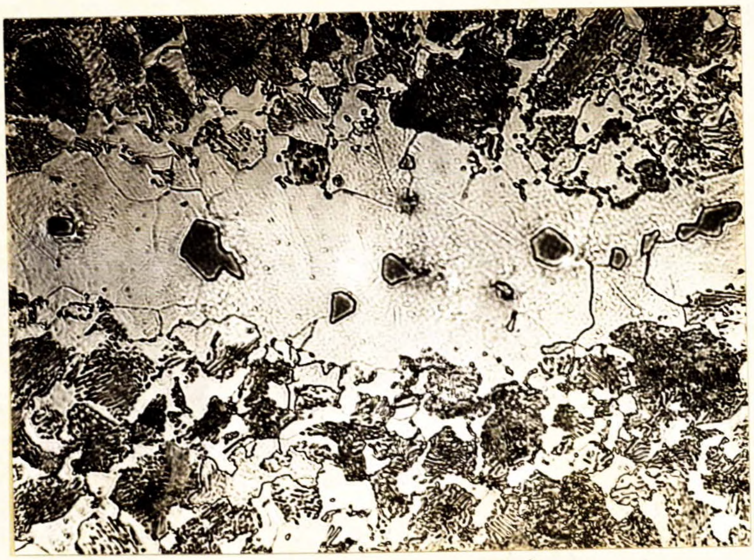
Figure 10.



X500, nital etch.

AREA UNAFFECTED BY THE
FLAME-HARDENING OPERATION.

Sample No. 2.

Note segregation caused by precipitation of ferrite around MnS inclusions during the casting period. Subsequent annealing operation leaves the segregation unaltered.

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