O T T A W A August 17th, 1943.

R E P O R T

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1476.

Examination of Cracked Gun Steel Ingots from the Dominion Foundries and Steel Limited, Hamilton, Ontario.

(Copy No. 10.)

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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Origin of Material:

On July 5th, 1943, Mr. F. Loosley, Works Manager, Dominion Foundries and Steel Limited, Hamilton, Ontario, submitted cracked sections of gun ingots for examination. In his covering letter, Mr. Loosley gives the approximate analysis of the steel and the following additional information:

"There was nothing unusual in the history of the heat up to the point of pouring ingots. They were stripped in the usual time, held for the usual time in the soaking

(Origin of Material, cont'd) -

pits, and heated in a normal manner. The first four ingots which we tried to forge broke up badly in the forging operation. The steel had the appearance of being hot short."

The samples submitted consisted of two flame-cut transverse sections of two ingots. One surface of each sample was machined subsequent to the cutting, to show the cracks.

A letter to Mr. Loosley requesting samples not flame-cut and showing fractured edges brought the following response: "I regret to say that all the steel from this particular heat was scrapped some time ago and we are unable to furnish you with any further samples."

Object of Investigation:

To determine the cause of cracking in these ingots.

Procedure:

1. The two smaller sections were deep-etched with 50 per cent muriatic acid, 10 per cent nitric acid in water for 24 hours. Figure 1 is a photograph typical of the two sections after etching.

2. Chemical analyses of one section were made at three locations; namely, outside, half-way to centre, and centre of the ingot. Table I, following, gives the results obtained and the approximate analyses supplied by Mr. Loosley:

(Continued on next page)

(Procedure, cont'd) -

Table I.

	Approximate Analysis Supplied.	OBTAINED Outside	Half-way	Centre
	- Per cent -			
Carbon -	0.28/0.32	0.31	0.30	0.20
Phosphorus -	0.030 max.	0.009	0.010	0.009
Sulphur -	0.030 max.	0.021	0.017	0.023
Manganese -	0.50/0.60	0.60	0.58	0.59
Silicon -	0.30 min.	0.36	0.37	0.36
Chromium -	2.00/2.25	1.091	1.84	1.87
Nickel -	0.70/0.90	1.07	1.05	1.03
Molybdenum -	0.40/0.50	0.43	0.42	0.40
Vanadium -	0.10	0.13	0.14	0.11
Boron -		None	None	None
Tin -		None	0.011	0.023

3. A small section, half-way to centre, was polished and given a light deep etch. Figure 2 shows this section after etching.

4. Specimens from the outside, half-way to centre, and centre, were polished and examined under the microscope. Figure 3 is a photograph of a condition common to the central and half-way-to-centre specimens. Figure 4 shows a fracture as a result of the condition shown in Figure 3. Figure 5 shows a sulphide stringer in a grain boundary, a frequent condition throughout the ingot.

5. Fracture tests were made on specimens machined from the above locations. Figures 6, 7, and 8 show the types of fractures obtained.

6. Samples were machined from the above locations, for a gas analysis. These specimens were forwarded to the laboratories of the Electro Metallurgical Company in Niagara

(Procedure, cont'd) -

Falls, New York, since we are not yet in a position to do this type of work. This company very kindly offered their assistance, which is hereby gratefully acknowledged. Table II gives the results obtained:

Table II.

Location	Oxygen	Hydrogen	Nitrogen
	- Percent -		
Outside - -	0.004	0.00011	0.006
Half-way to centre -	0.004	0.00014	0.0066
Centre - -	0.004	0.00018	0.009

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Discussion:

The deep-etched sections show no evidence of gross segregation, and this is confirmed by the chemical analysis at the three different areas. The chromium content is lower and the nickel content higher than the analysis ranges given but this would have no bearing on the problem of cracking.

The light deep etch shows intercrystalline cracking. A microscopic examination of the central and half-way-to-centre specimens reveals gas segregation at the boundaries of the primary austenite grains. In a great number of cases these gas holes have linked up to form cracks which, of course, follow the grain boundaries. These gas holes occur only inside the area rapidly chilled by the ingot mould. This is to be expected from the mechanics of cooling. The outer layers of the ingot are cooled rapidly and the gases are entrapped in the rapidly cooling steel and have no opportunity to segregate. As shown by the fracture tests, hydrogen in the outer layers has had no chance to diffuse away. In the central regions of the ingot the rate of cooling is slower and the gases, coming out

(Discussion, cont'd) -

of solution, are thrust to the grain boundaries.

It should be emphasized, however, that gas segregation would not make the steel hot short. The intercrystalline cracking, due to gas segregation as found in the ingot samples, would occur only at temperatures in the neighbourhood of 400° F. Above that temperature the gases would still be in solution and have no embrittling effect.

The fracture tests all show the bright areas of hydrogen occlusion. The hydrogen has probably resulted from accidental contamination in the furnace or, possibly, from pouring during high-humidity weather conditions. It is well recognized that steels of this type very readily absorb hydrogen and special precautions are necessary in their manufacture. The low gas contents shown by the gas analyses are not surprising in view of the badly cracked condition of the steel. Gases trapped in the cooling steel have numerous avenues of escape to the outside of the ingot. In addition, the flame-cutting of the samples would greatly assist the escape of the gases. It should also be recognized that the present-day method of gas analysis of steels is not consistently reliable and much work remains to be done in this field.

In the central two-thirds of the ingot numerous long stringers of sulphides in the grain boundaries were found; these would reduce the impact strength at high temperatures. The fact that these sulphides appear as long stringers, and not as globules, indicates that the rate of cooling of the ingot in the ingot mould was fairly rapid.

A visual examination of the sections (see Figure 1) would seem to indicate that there is more than one cause of cracking in the ingots. A great many cracks are confined to the central two-thirds of the ingots. This is typical of

(Discussion, cont'd) -

cracks resulting from too rapid cooling or too rapid reheating to rolling temperatures, producing high thermal stresses. In addition, the ingot surface is very rough, indicating the use of a fire-checked mould. The impeded contraction on cooling, caused by the metal being locked in the mould surface depressions, results in cracks in the centre of the flutes. Unless the metal is free to contract away from the mould walls, the contraction stresses will readily tear the hot metal.

To summarize, there are two evidences of rapid ingot cooling; elongated stringers of sulphides, and typical cooling cracks. This would indicate that the ingots were banked before rolling and allowed to cool to a fairly low temperature. Outside of sulphide stringers, nothing has been found which would make the ingots hot short. There only remains a possibility of the ingots being cracked before forging was attempted.

It will be evident from the above that there is no single cause of cracking which can be demonstrated in test results or photomicrographs. The relation of gas holes at the grain boundaries to intercrystalline cracking is clear. The additional weakness induced by sulphide stringers is also demonstrable and points to faulty deoxidation and ingot practice. Beyond this, nothing other than conjecture can explain the severity of the cracking. It is suggested that the heat history be examined in the light of the above information.

Conclusions:

1. The cracking of these ingots is not due to chemical segregation.

2. Gas occlusion and precipitation at grain boundaries is responsible for the intercrystalline cracking

(Conclusions, cont'd) -

at low temperatures.

3. Fracture tests indicate hydrogen to be a factor in the cracking.

4. Additional causes may be:

(a) Too rapid cooling or too rapid reheating to forging temperatures.

(b) The use of fire-checked moulds.

(c) Faulty deoxidation practice.

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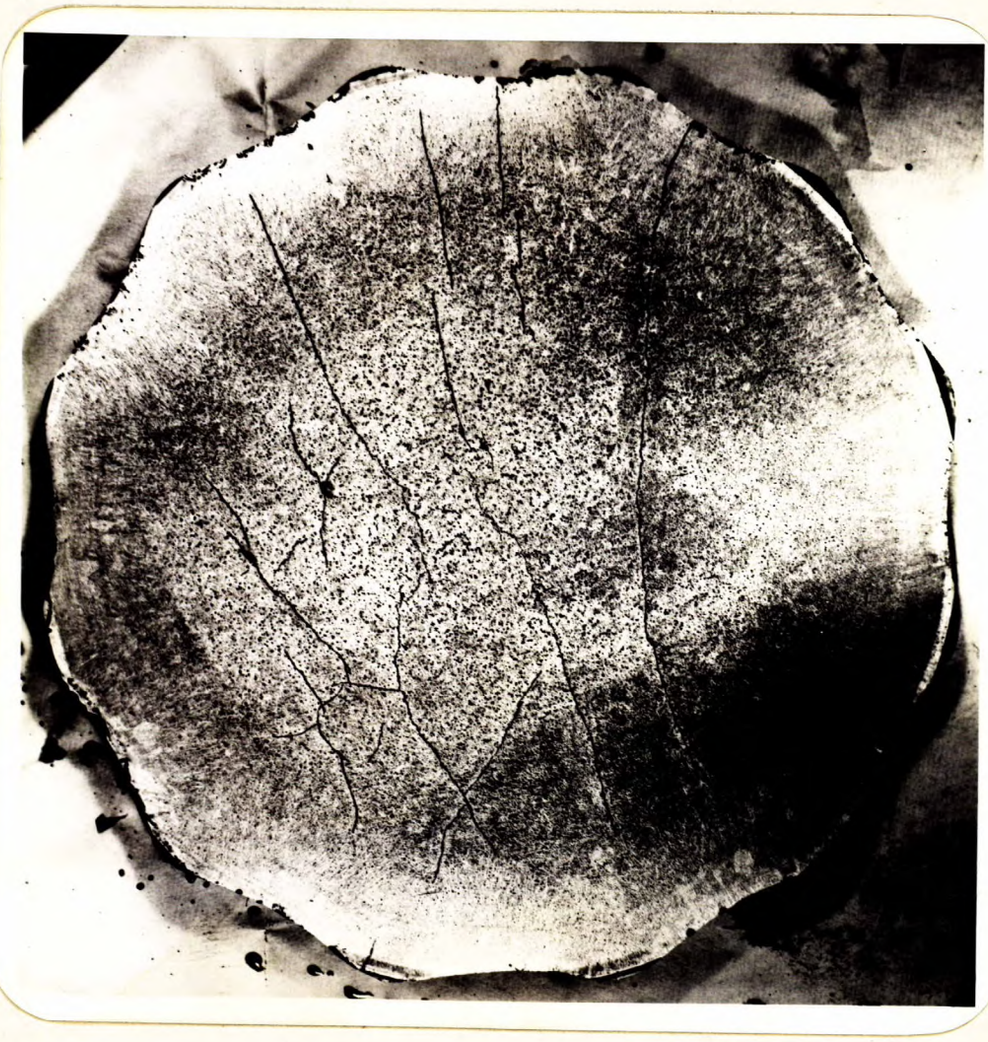
Figure 1.



SMALL SECTION OF INGOT AFTER DEEP ETCH;
TYPICAL OF BOTH SECTIONS.

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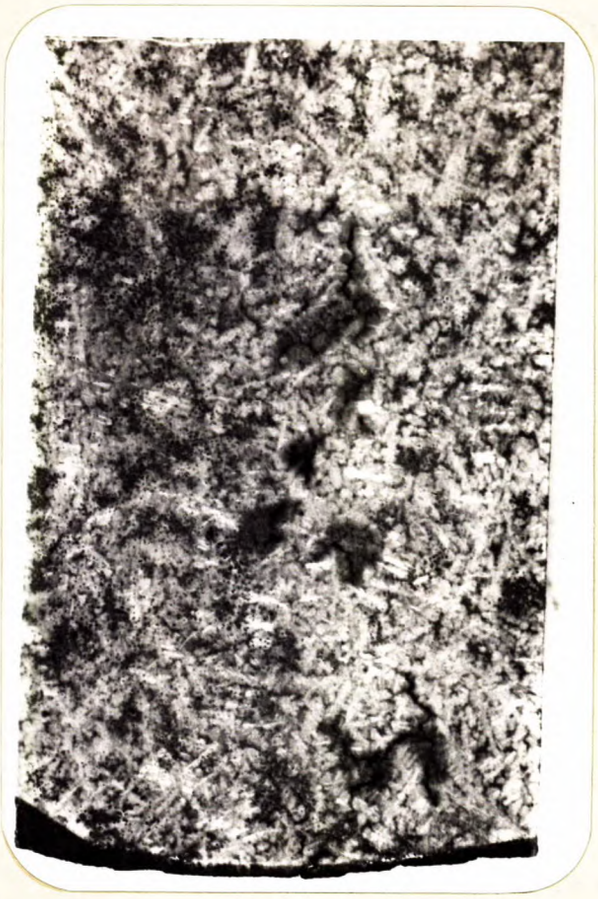
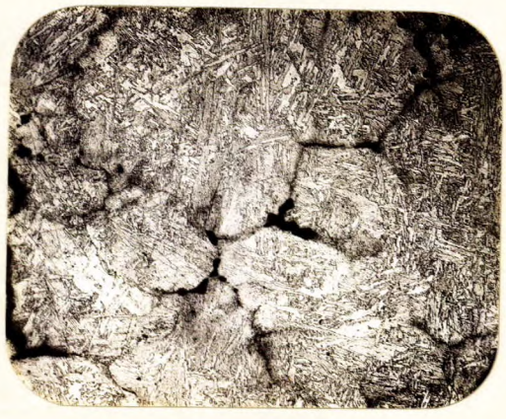
Figure 2.



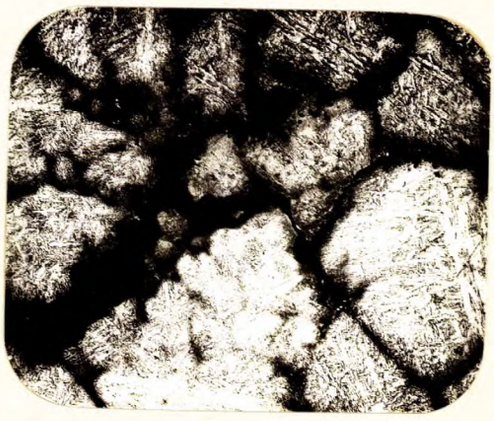
X3, etched in 50 per cent hydrochloric acid.
LIGHT DEEP-ETCHED SECTION, HALF-WAY TO CENTRE.
Note numerous intercrystalline cracks.

Figure 3.



X100, etched in
2 per cent nital.
GAS HOLES AT
GRAIN BOUNDARIES.

Figure 4.



X100, etched in
2 per cent nital.
CRACK RESULTING FROM
LINKING UP OF GAS HOLES.

Figure 5.

X250, etched in 2 per cent nital.
SULPHIDE STRINGER IN GRAIN BOUNDARY.

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Figure 6.

FRACTURED SPECIMEN SHOWING
TYPICAL BRIGHT AREAS DUE TO HYDROGEN.

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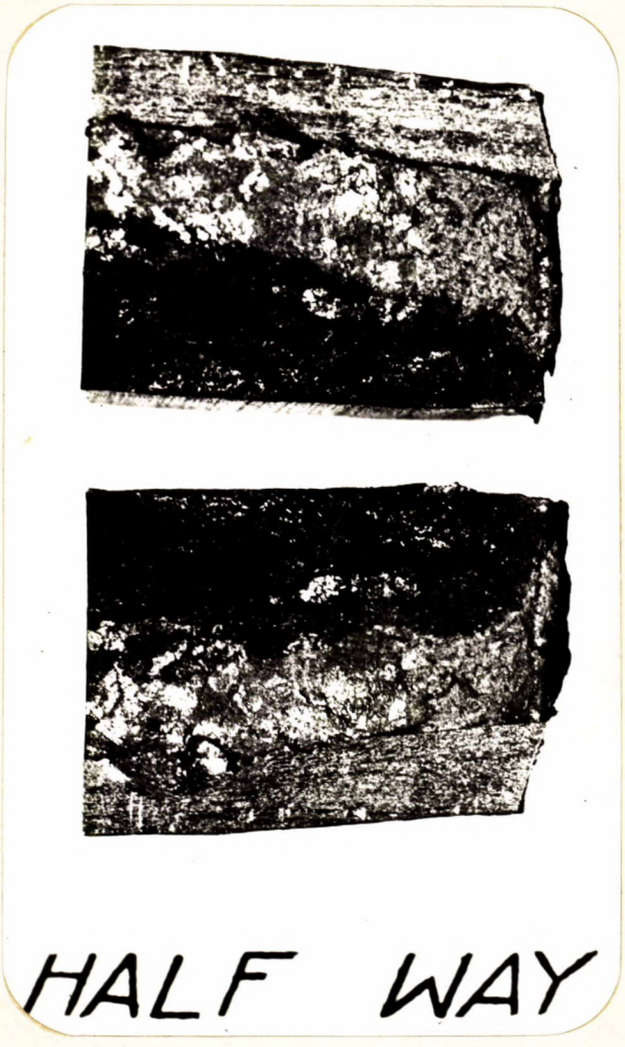
Figure 7.



FRACTURED SPECIMEN SHOWING
TYPICAL BRIGHT AREAS DUE TO HYDROGEN.

Figure 8.

FRACTURED SPECIMEN SHOWING
TYPICAL BRIGHT AREAS DUE TO HYDROGEN.

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