File

OTTAWA January 2, 1945.

R E P O R T

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1768.

Metallurgical Examination of Defective
4.5-Inch Shell Forgings.

(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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Description of Material and Object of Investigation:

On November 22, 1944, two sections from a 4.5-inch shell forging (see Figure 1) from the Trenton Steel Works, Trenton, Nova Scotia, were submitted, under Analysis Requisition No. O.T. 4304, by Mr. H. H. Scotland, Inspector of Materials, Inspection Board of United Kingdom and Canada, Ottawa, Ontario. The covering letter (File No. P.O. 935) requested a check on the chemical analysis and that "an endeavour be made to ascertain under the microscope the quality of the steel".

Correspondence submitted by Mr. Scotland supplied the following information:

1. (a) Average temperature of billets - 2100° F.
   (b) After-forging temperature of billets - 1810° F.
   (c) Soaking time of ingot in furnace before forging - 13 hours.

2. "The defects which appear in the samples were discovered recently in the wall of the forgings. The condition appears to be local in the heat, as for instance, it has been discovered in three separate heats so far, and in each case has been apparent in only one ingot."

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

Figure 1.

GENERAL VIEW OF ONE OF THE SECTIONS SUBMITTED OF A 4.5-INCH SHELL FORGING, SHOWING DEFECTS IN THE CAVITY.

(Approximately 5/6 full size).

Visual Examination:

Visual examination of the sections showed irregular veinlike cracks extending throughout the surface of the cavity. No evidence of these defects was discovered on the outer surface of the shell forgings.

Chemical Analysis:

A chemical analysis was made on a sample taken from one of the sections submitted. The results are compared with the analysis submitted by Mr. Scotland.

		AS FOUND	SUBMITTED BY MR. SCOTLAND
		- Per Cent -	
Carbon	-	0.55	0.53
Manganese	-	0.82	0.83
Silicon	-	0.23	0.29
Sulphur	-	0.027	0.028
Phosphorus	-	0.028	0.036
Nickel, chromium, molybdenum	-	Nil.	

Heat-Treating Test:

Two samples were cut from one of the submitted pieces and then heated in a furnace at the following temperatures, followed by air cooling:

(a) 2460° F.
(b) 1800° F.

Microscopic Examination:

Sections were cut from the pieces submitted and photomicrographs were taken.

Figure 2 is a photomicrograph of a cross-section, at X100 magnification, showing the depth and character of the "crack" at the cavity surface. Note, also, the round holes visible near the surface.

Figure 3, taken at X100 magnification, shows another of the "cracks" at the cavity surface. This is also taken along the cross-section.

Figure 4 is a photomicrograph, at X100 magnification, also along the cross-section, etched in nital, showing the concentration of ferrite around the hole at the surface of the cavity.

Figure 5, taken at X100 magnification, shows the microstructure and grain size of the steel at the centre of one of the sections.

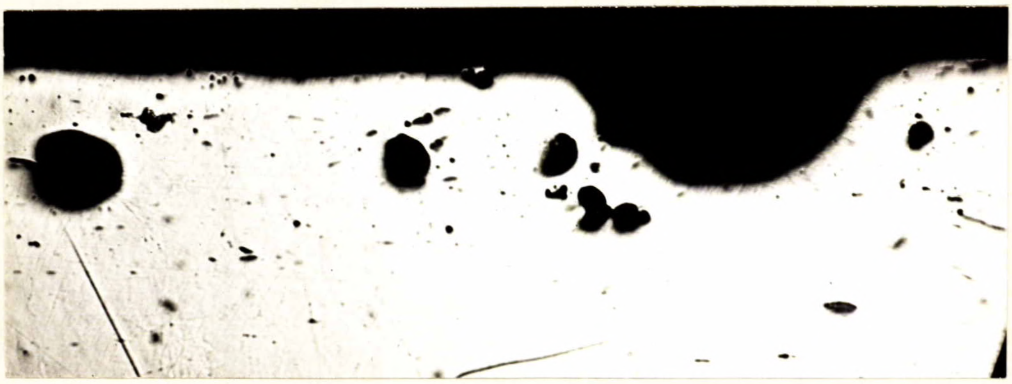
Figure 6, taken at X100 magnification, shows the huge grain size occurring at the edge of one of the sections submitted.

Figure 7 is a photomicrograph, at X100 magnification, showing the grain size produced by heating a sample of the steel at 2460° F., followed by air cooling.

Figure 8 (magnification, X100) shows the grain size produced by heating a sample to 1800° F., followed by air cooling.

(Figures 2 to 8 follow,)
(on Pages 4 to 7.)

Figure 2.



X100, unetched.

CROSS-SECTION SHOWING DEPTH OF "CRACK"
AND HOLES NEAR SURFACE OF CAVITY.

Figure 3.

X100, unetched.

CROSS-SECTION SHOWING DEPTH AND CHARACTER
OF "CRACK" AT THE SURFACE OF CAVITY.

Figure 4.

X100, nital etch.

CROSS-SECTION SHOWING HOLE
AT SURFACE OF CAVITY.

Note concentration of ferrite,
suggestive of melting.

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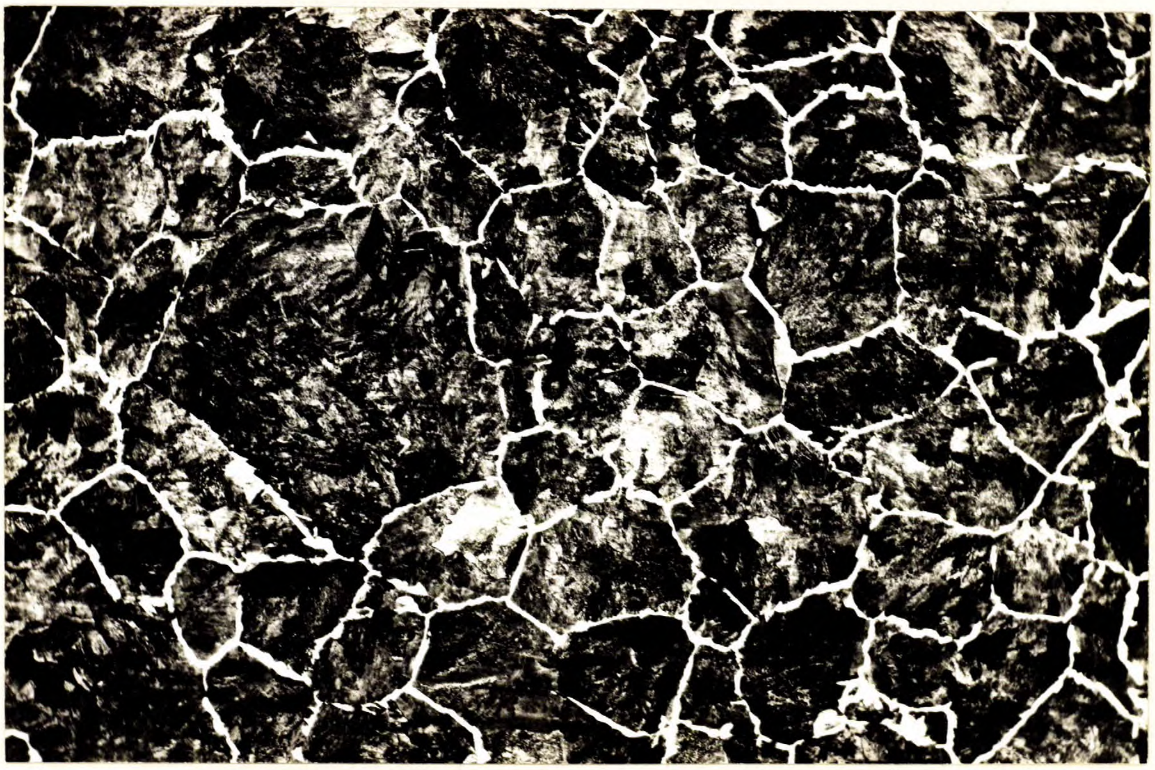
Figure 5.



X100, nital etch.

MICROSTRUCTURE AND GRAIN SIZE AT
CENTRE OF ONE OF THE SECTIONS.

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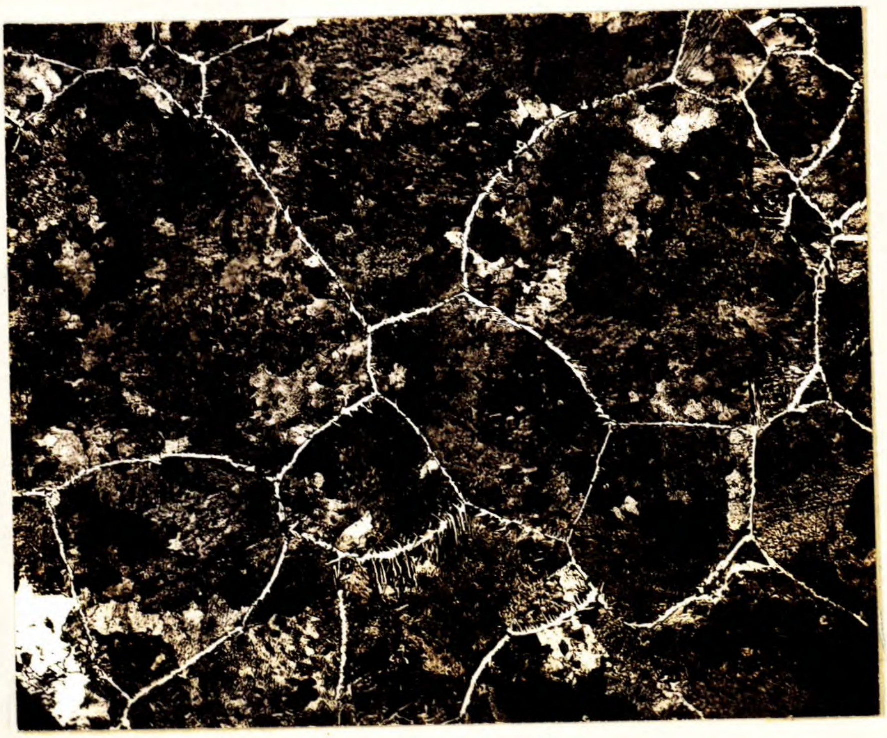
Figure 6.

X100, nital etch.

HUGE GRAIN SIZE AT EDGE OF
ONE OF THE SECTIONS.

Figure 7.



X100, nital etch.

GRAIN SIZE RESULTING FROM HEATING
STEEL AT 2460° F., FOLLOWED BY AIR COOLING.

Figure 8.

X100, nital etch.

HEATED AT 1800° F.; AIR COOLED.

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DISCUSSION AND CONCLUSIONS:

The chemical analysis indicated that the steel was satisfactory from the point of view of chemical content.

Microscopic examination of specimens in the unetched condition very clearly showed that the defects or "cracks" were quite shallow, as shown in Figures 2 and 3. Holes quite round in shape were also evident along the edge of the cavity (see Figure 2). These holes were found to be round both in the cross-section and in the longitudinal section, thus proving that they were formed after the forging operation.

Examination of the steel in the etched condition revealed grains of such magnitude (see Figures 5 and 6) that overheating or burning was immediately suspected. Consequently, a sample was heated at 2460° F., approximately 90° F. below the melting point for this steel. The resulting grain size, shown in Figure 7, is actually smaller than that of Figure 6, thus

(Discussion and Conclusions, cont'd) -

proving that the outer parts of the forging must have been heated to a temperature in the neighbourhood of the liquidus.

Since the maximum recommended forging temperature for steel of this type is 2300° F., it is obvious that a temperature considerably beyond this maximum had been reached.

The opinion that burning had occurred at the surface of the cavity is further supported by the microstructure shown in Figure 4, which discloses a hole surrounded by ferrite, an indication of free oxygen in the furnace atmosphere, a condition which would promote burning when the forging temperature is high.

The finishing temperature of a forging of this carbon content should be approximately 1800° F. A specimen was therefore heated at 1800° F. and air-cooled. The resulting grain size is shown in Figure 8.

The following conclusions were arrived at:

1. The defects or "cracks" are shallow in depth.

2. The very large grain size and surface porosity indicate excessive surface temperatures, actually reaching the melting point.

3. The defects occurring at the cavity surface were caused by temperatures sufficiently high to cause burning. Presence of ferrite at the base of some defects indicated the presence of free oxygen in the furnace atmosphere, a condition which would promote burning.

Recommendations:

1. It is recommended that any shell showing these defects be discarded, because their presence indicates that excessive temperatures have been reached.

2. Forging temperatures should be carefully controlled

(Recommendations, cont'd) -

in order to avoid the possibility of heating beyond the maximum of 2300° F.

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