OTTAWA April 26, 1945.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1854.

Metallurgical Examination of Flame-Hardened
Cast Iron Cylinder Blocks.

(Copy No. 10.)

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

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Origin of Material and Object of Investigation:

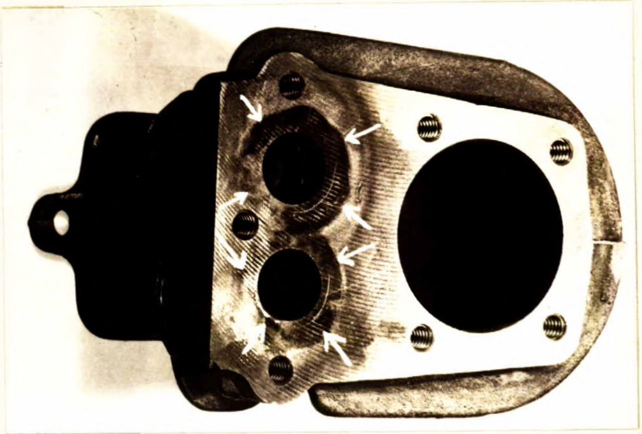
On March 8, 1945, four cast iron cylinder blocks (see Figure 1) from the air-cooled engine used to drive a 300-watt charging set were submitted, for metallurgical examination, by Col. R. A. H. Galbraith, Director of Signals and Engineering, Inspection Board of United Kingdom and Canada, 479 Bank Street, Ottawa, Ontario, under requisition File No. 4/14/10/9, c.c. D6/S/118.

The covering request letter, dated March 7, 1945, stated that three of the blocks were flame-hardened at the valve seat to varying hardnesses. The fourth was a standard block not hardened. It was requested that a metallurgical examination be made to determine the hardness number most suitable for the function which the material has to perform.

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

For purposes of identification, the flame-hardened blocks had been assigned numbers 1, 2 and 3, and the standard block, number 4.

Figure 1.



FLAME-HARDENED CAST IRON CYLINDER BLOCK.
Note flame-hardened valve seats.
(Approximately 2/5 actual size).

Magnaflux Examination:

The flame-hardened cast iron cylinder blocks were magnafluxed in order to ascertain the presence of cracks in the flame-hardened areas. No cracks were evident.

Chemical Analysis:

The results of the chemical analysis performed on each of the four blocks are compared in Table I with the recommended chemical limits for a cast iron intended for flame hardening.

(Continued on next page)

(Chemical Analysis, cont'd) -

TABLE I.

	Block No. 1	Block No. 2	Block No. 3	Block No. 4	Recommended*
	- Per Cent -				
Total carbon -	3.49	3.50	3.46	3.46	3.3 max.
Combined carbon -	0.65	-	-	-	
Manganese -	0.85	0.80	0.87	1.02	0.6 to 1.0
Silicon -	2.20	2.20	2.40	2.24	1.0 to 2.0
Sulphur -	0.073	0.077	0.065	0.074	
Phosphorus -	0.221	0.227	0.218	0.168	
Nickel -	0.1	0.1	0.1	0.1	1.0 to 2.0
Chromium -	Trace.	Trace.	Trace.	Trace.	0.75 max.
Molybdenum -	Trace.	Trace.	Trace.	Trace.	" "
Vanadium -	Nil	Nil	Nil	Nil	" "

Macro-Examination:

Sections adjacent to the flame-hardened valve seats were cut, polished, and etched in 2 per cent nital, in order to reveal the extent of the heat-affected zones. Figure 2 shows the extent of the hardened zones on the surface along the valve seats. Figure 3 is a cross-section from Block No. 1, showing the depth of the hardened zone (approximately 1/20 inch).

Hardness Examination:

The results of hardness tests made on hardened and unhardened portions of the cylinder blocks are given in Table II. Rockwell "A" readings are converted to Rockwell "C".

TABLE II. - HARDNESS.

	Block No. 1	Block No. 2	Block No. 3	Block No. 4
	Hardened Areas			
Rockwell "A"	60-70	62-69.5	62-73	-
Rockwell "C"	20-41	23-38	23-45	
	Unhardened Areas			
Rockwell "A"	51.5	51.5	50	50.5

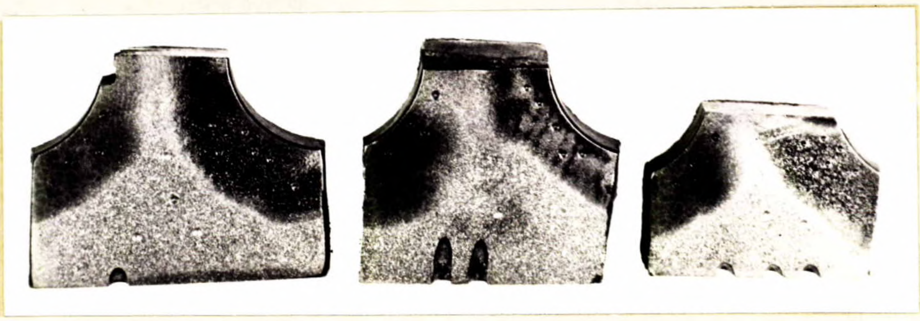
(Continued on next page)

* In "Flame Hardening of Cast Iron," by F. G. Sefing, IRON AGE, Oct. 19, 1939.

Microscopic Examination:

Photomicrographs (Figures 4 to 9, all at X500 magnification) were taken from hardened and unhardened sections of the flame-hardened cylinder blocks. Figures 4 and 5 show the unhardened and hardened portions, respectively, of Block No. 1; Figures 6 and 7 show those of Block No. 2; and Figures 8 and 9 are taken from Block No. 3.

Figure 2.



SECTIONS CUT FROM BLOCKS (NITAL ETCH), SHOWING EXTENT OF HARDENED ZONE ON THE SURFACE ALONG VALVE SEATS.

(Approximately 1½ times actual size).

Figure 3.

SECTION FROM CYLINDER BLOCK No. 1 (NITAL ETCH), SHOWING DEPTH OF HARDENED ZONE (1/20 INCH).

(Approximately 2 3/5 actual size).

(Microscopic Examination, cont'd) -

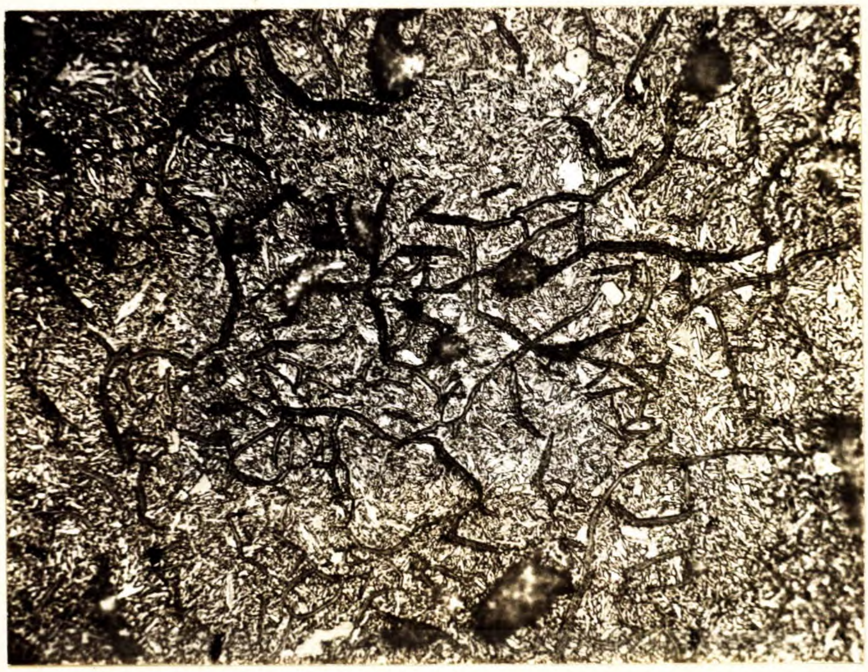
Figure 4.

X500, nital etch.

CYLINDER BLOCK NO. 1.

Unhardened zone showing pearlite, ferrite, and graphite.

Figure 5.



X500, nital etch.

CYLINDER BLOCK NO. 1.

Hardened zone showing martensite and graphite.

(Microscopic Examination, cont'd) -

Figure 6.

X500, nital etch.

CYLINDER BLOCK NO. 2.

Unhardened zone showing pearlite, ferrite, and graphite.

Figure 7.

X500, nital etch.

CYLINDER BLOCK NO. 2.

Hardened zone showing martensite and graphite. Phosphide eutectic also evident.

(Microscopic Examination, cont'd) -

Figure 8.

X500, nital etch.

CYLINDER BLOCK NO. 3.

Unhardened zone showing ferrite, pearlite, and graphite.

Figure 9.

X500, nital etch.

CYLINDER BLOCK NO. 3.

Hardened zone showing martensite and graphite. Phosphide eutectic also evident.

Discussion:

The macro-examination reveals that the valve seats were hardened at the surface for a distance of approximately 5/16 inch around the valve holes. The depth of hardening varied to a maximum of 1/20 inch. Cylinder Block No. 2 appeared to have a more shallow hardened layer than did Blocks Nos. 1 and 3.

Hardness tests performed with a Rockwell "A" hardness tester indicated a wide range of readings in the hardened areas. This range (60 to 73 Rockwell "A", or 20 to 45 Rockwell "C") was common to all three blocks and no appreciable difference was discernible. A correctly flame-hardened cast iron of proper chemical composition should produce an average hardness of 70 to 75 Rockwell "A", or 40 to 50 Rockwell "C".

The microscopic examination supported the evidence disclosed by the chemical analyses and hardness tests, that is, that all three cylinder blocks had been made of essentially the same materials and the microstructures of the hardened areas were similar. It should be noted that considerable areas of free ferrite are evident in the unhardened areas. Apparently the rate of chilling for this particular casting was such that it was impossible to produce a pearlitic iron from this silicon material. Because of the considerable quantities of free ferrite, thus indicating a low combined carbon content, the iron could not be expected to attain a high hardness value on flame hardening, as is desirable.

A comparison of the chemical content with that of a recommended flame-hardening cast iron (see foot-note, Page 3) is given in Table I. It is to be noted that the total carbon and silicon contents exceed the recommended maximum, and it is reasonable to assume that inadequate hardening resulted because of an excess of these elements and also because of

(Discussion, cont'd) -

the lack of alloying elements. The time intervals in flame hardening are exceedingly short and those irons which are more susceptible to the ordinary hardening treatment will likewise respond much better to the flame-hardening treatment.

A grey cast iron may be considered a steel with excess carbon in the form of graphite. Because of the high silicon content, considerable areas of ferrite are present. These ferrite areas act as a source of nucleation, resulting in high temperature transformation products and a consequently low hardness material. The lack of alloying elements results similarly in that the cooling rate is insufficient to prevent the cutting of the nose of the S-curve, thus resulting in high temperature transformation products, and hence the iron would be soft.

Variation in surface hardness may have been caused by the use of flame of varying intensity.

The shallow depth of hardness (less than 1/20 inch) would be considered inadequate. The depth of the hardened layer is generally controlled by using a constant intensity of the oxy-acetylene flame and varying the speed of the flame travel. The slower the speed the more heat is developed at the skin and the greater the penetration. A depth beyond 5/16 inch would result in the burning of the surface metal and the presence of excessive quenching stresses with a consequent distortion. The deleterious conditions can be minimized by the use of alloying elements.

Conclusions:

1. Hardness values obtained on the flame-hardened valve seats were considerably below that required. The average surface hardness obtainable by flame-hardening cast iron should be from 70 to 75 Rockwell "A" or 40 to 50 Rockwell "C".

(Continued on next page)

(Conclusions, cont'd) -

2. The depth of the hardened layer was also inadequate (1/20 inch maximum).

3. No appreciable difference in the hardened areas of the three cylinder blocks was observed.

4. Poor hardening properties were probably caused by the use of a cast iron too high in silicon and carbon, and by the lack of alloying elements.

5. Non-uniformity of surface hardness may have been caused by the use of a flame of varying intensity.

Recommendations:

1. It is recommended that a cast iron having the following chemical limits be employed for flame hardening,[*] if available:

		Per Cent
Total carbon	-	3.3 max.
Manganese	-	0.6 to 1.0
Silicon	-	1.0 to 2.0
Nickel	-	1.0 to 2.0
Chromium, Molybdenum, Vanadium	-	0.75 max.

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AF:LB.

[*] See foot-note, Page 3.