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EXAMINATION OF A DEFECTIVE ("PINHOLED") STEEL CASTING FROM FORD MOTOR COMPANY OF CANADA LIMITED, WINDSOR, ONT.

by

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PHYSICAL METALLURGY DIVISION

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SUMMARY

Defects in a portion of a steel casting were identified as being subsurface voids commonly known as pinhole porosity. The most satisfactory theory of the mechanism by which this defect occurs is presented. Also, numerous foundry conditions which may contribute to the formation of pinholes are cited.

The general inclusion content of the steel was considered to be typical of that normally found in medium carbon steel deoxidized with aluminum and retaining 0.054 percent of aluminum.

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INTRODUCTION

Under a covering letter dated March 3, 1958, Mr. G.E. Fellows, Superintendent, Foundry, Ford Motor Company of Canada Limited, Windsor, Ontario, submitted a portion of a defective casting for metallurgical examination "to determine just what the inclusions are in the metal and whether they are the results of gas, etc., coming out of the metal or being forced into the metal surfaces from the sand".

COMPOSITION

The results, in weight percent, of chemical analyses of drillings were:

C	Mn	Si	S	P
0.36	0.68	0.35	0.031	0.057

The total aluminum content was found, by quantitative spectrographic analysis, to be 0.054%.

The results of semi-quantitative spectrographic analysis were (in percent):

Mn	Si	Cr	Mo	V	Zn	Mg	Sn	Cu	Co	Ni
0.9	0.4	0.08	0.03	0.004	0.02	0.009	0.004	0.2	0.002	0.2

MACRO EXAMINATION

The fractured surface of the casting is shown in Figure 1*. The general surface of the fracture was dull grey in colour with a dendritic, columnar texture; however, numerous cavities, originating at or just below the cast surface, were present. The elongated cavities were located normal to the outer surface of the casting. Both ends of the cavities tended to be sharp. The width of the

*All figures are assembled at the end of the report.

cavities ranged up to about 3/32 inch, while their length ranged to over 1/2 inch. The walls of the cavities were relatively smooth and while a few were bright most of the walls were coated with a dark high-temperature oxide scale.

Numerous "pinholes" were observed on the outer, shot-blasted surface of the casting.

MICROSTRUCTURE

Sections, located normal to the cast surface, were prepared for metallographic examination.

Figures 2 and 3 show the general structure observed about the innermost end of the cavities. Figures 4 and 5 show some details not readily apparent in Figures 2 and 3. These photomicrographs show cavities which were empty except for a coating of high-temperature iron oxide scale. No inclusions were observed in any cavities. The lower left areas of Figures 2 to 5, inclusive, contain a rare cluster of alumina inclusions. The metal adjacent to the walls of the cavities was decarburized (Figs. 3 and 5) and contained numerous particles of subscale (Fig. 4).

Figures 6 and 7 indicate the inclusions, mostly manganese sulphide and duplex sulphides and silicates, which were observed to prevail in areas well removed from the cast surface.

SUMMARY AND DISCUSSION

The casting was found to be made of plain medium carbon steel in which no abnormal residual elements were revealed by spectrographic analysis. The total residual aluminum content was 0.054% by weight. Normally this amount of aluminum is sufficient to prevent the formation of pinholes. However, the voids, in every respect, were typical of pinhole porosity.

Sims and Zapffe (1) have developed the following, and most generally satisfactory, theory of pinhole formation:

"Almost immediately after the molten steel contacts the cold, moist sand, a thin skin of solid steel forms. At the same time the water in the adjacent sand is changed to steam, with an increase of some 5,000 volumes, and creates an atmosphere highly oxidizing to steel. A portion of this water vapour escapes through the porous sand, but some of it reacts with the solid steel thus:

$$H_2O + Fe \longrightarrow 2\,H + FeO$$

The FeO is formed as a surface layer. The released atomic hydrogen readily dissolves, and the rate of diffusion is so great at temperatures just under the freezing point that it flows through the thin layer of solid steel about as readily as the water vapour penetrates the facing sand. A higher concentration of hydrogen is built up in the liquid steel.

When the hydrogen concentration becomes high, the hydrogen will react with dissolved FeO in the steel to form a small bubble of water vapour on the frozen wall. Immediately the hydrogen from the adjacent liquid steel, as also that still diffusing through the solid layer, will begin diffusing into the bubble and collecting to form molecular hydrogen. Thus, the bubble grows."

Sims and Zapffe illustrated their theory with Figure 8, which is a diagrammatic sketch of the origin and growth of pinholes.

A good discussion of pinholes and their prevention is given by C.W. Briggs(2). According to him, some of the conditions responsible for the presence of hydrogen, which is necessary for the formation of pinholes, are as follows:

"<u>Effect of Steelmaking on Pinhole Porosity</u> - An effort should be made to produce steel with a low hydrogen content. The sources of hydrogen in the fluid steel are or include:

1. Hydrogen introduced into the charge by wet, rusty, or oily scrap.

2. Water vapour or steam in the air employed for combustion and in the furnace atmosphere.

3. Water vapour formed by combustion of hydrogen in the fuel.

4. Moistened slag-making materials, slaked lime, wet ore, or wet refractory materials.

5. Holding of heats and the arcing on heats in the furnace after the final deoxidizers have been added.

6. Use of wet ferroalloy additions.

Hydrogen absorption from the furnace atmosphere is determined mainly by the humidity of that atmosphere. The humidity varies greatly as the weather changes. All materials added to the bath should be dry, and all water-pipe connections should be regularly inspected to prevent water from leaking into the furnace or refractories.

The only agency for driving hydrogen out of the bath is the so-called "boil". The CO bubbles escaping from the bath act as a carrier of the hydrogen from the bath through the mechanism of diffusion of the hydrogen into the CO bubble. A long vigorous boil during the oxidizing period is necessary for low hydrogen content. With ample carbon in the metal, such as 0.20% or more, the boil should be brisk; i.e., the escaping bubbles should almost crowd each other.

<u>Effect of Tapping and Pouring Conditions on Pinhole Porosity</u> - Volatile matter in the furnace spout, wet furnace spouts, insufficient dryness of ladles, lack of steam vents in ladles, and volatile matter in ladle lining can each add to the increase of hydrogen in the melt.

Old sculls in ladles receiving molten metal, exposure of metal to a number of transfers, inadequate deoxidation by special deoxidizers, ladle additions of alloys, and dipping used skimming rods into metal in the ladles may also be responsible for hydrogen pickup or may cut down the effectiveness of the aluminum deoxidizers.

<u>Effect of the Mold on Porosity</u> - The initial hydrogen content of a steel will influence its tendency to form pinholes. Such factors as excess moisture content, low permeability of the facing sand, casting contours, excess organic bonding materials, or any condition that will build up a high pressure of water vapour or hydrogen on the face of the casting, will contribute toward a flow of hydrogen into the casting and will therefore determine the prevalence of pinholes. Moisture in the mold is probably the most outstanding source of hydrogen, and the steam

generated by the molten metal is the most virulent form of inoculator. Green sands and mold washes have long been recognized as sources of moisture.

Thus a steel that is high in hydrogen content may not produce a casting containing pinhole-porosity defects if the molds are such that hydrogen or water vapour is not formed. If hydrogen is not formed by the mold to react with the oxygen of the metal, or if the aluminum deoxidizer has reduced the available oxygen in the metal to a low content, then pinholes should not be found."

Most of the inclusions remote from the surface are manganese sulphides and duplex sulphides and silicates. These inclusions were present in normal amounts. Occasional clusters of alumina were present. The fine particles of subscale in the decarburized surface skin of the casting may be formed by oxygen diffusing into the steel at elevated temperatures and preferentially combining with silicon and possibly manganese.

REFERENCES

1. Sims, C.E., and Zapffe, C.A., The Mechanism of Pin-hole Formation. Trans. A.F.A., vol. 49, pp. 255-281, 1941.

2. Briggs, C.W., Metallurgy of Steel Castings. McGraw-Hill, New York, 1946.

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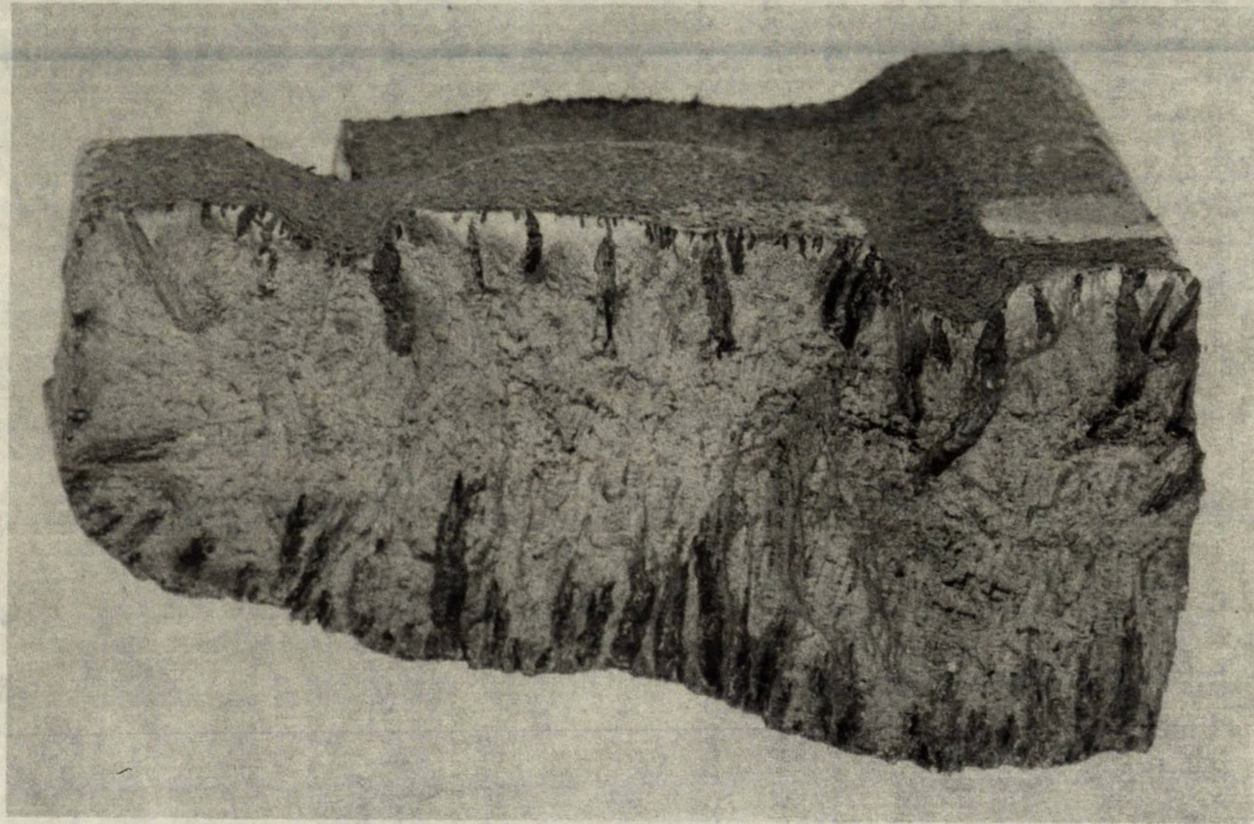
(Figures 1-8 follow,)
(on pages 6 to 10.)



(Twice actual size)

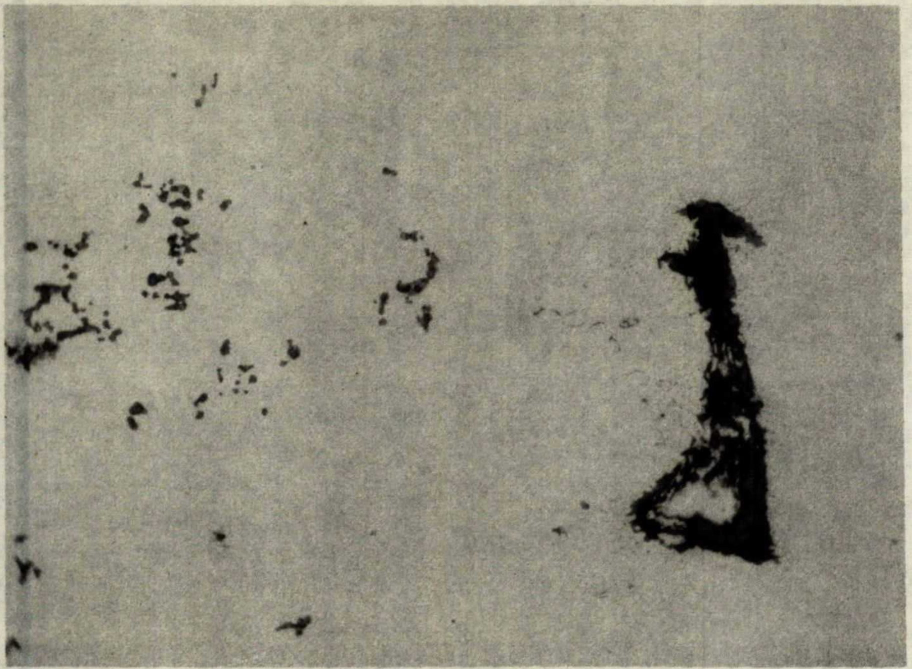
Fig. 1. - Fractured cross-sectional surface of the casting, in the as-received condition.

(Unetched; X100)

Fig. 2. - Field oriented normal to, but just below, a cast surface.

(Nital etch; X100)

Fig. 3. - Same field as shown in Fig. 2.



(Unetched; X500)

Fig. 4. - Enlarged lower, left-of-centre portion of the field shown in Fig. 2.

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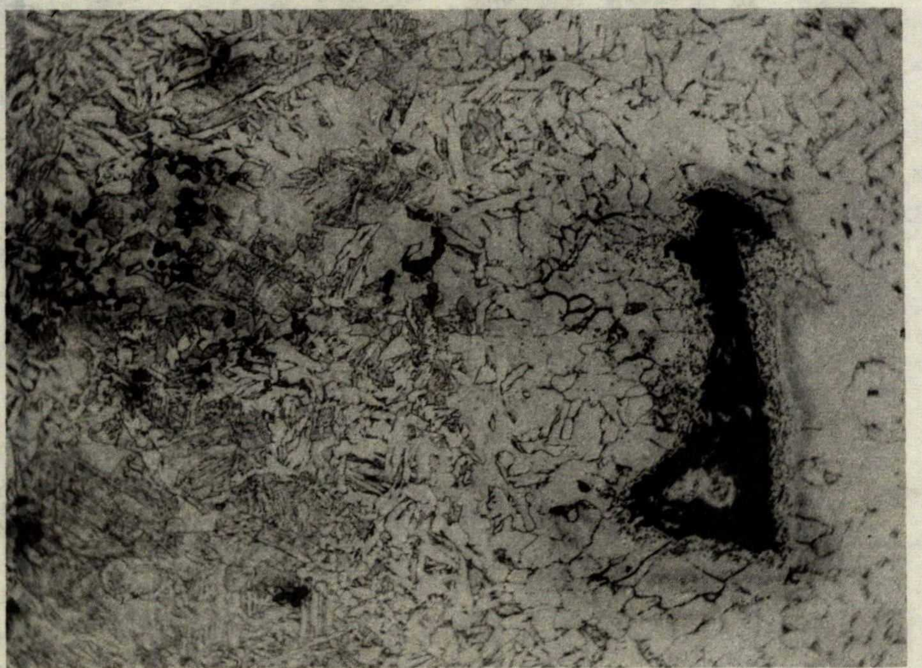

(Nital etch; X500)

Fig. 5. - Same field as shown in Fig. 4.

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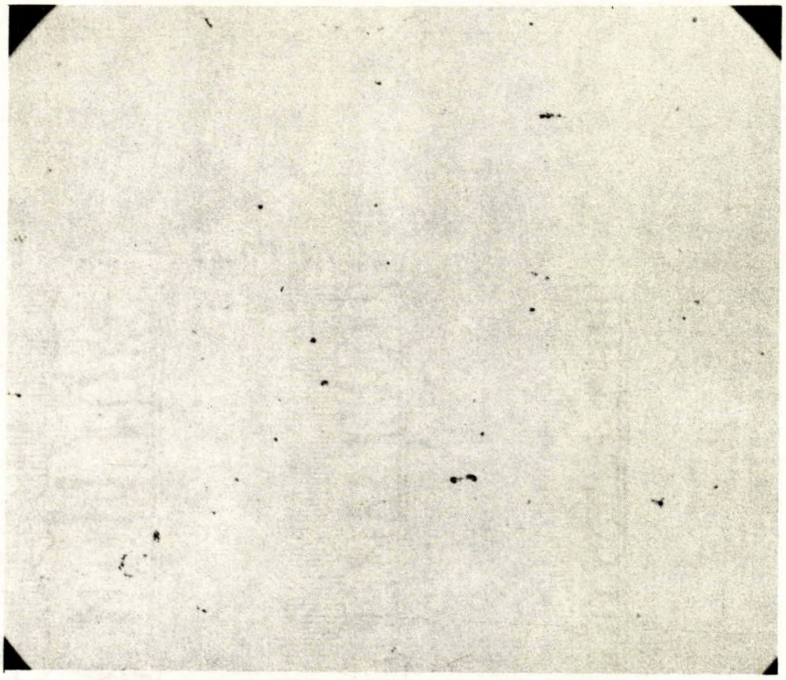
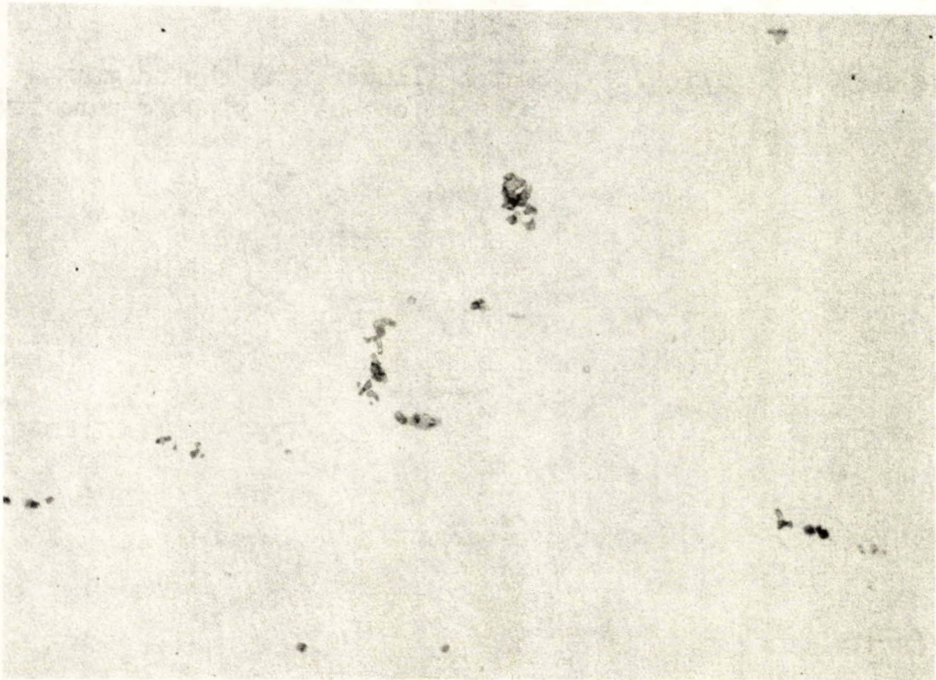


(Unetched; X100)

Fig. 6. - Typical field of inclusions from the sound interior of the casting



(Unetched; X500)

Fig. 7. - Enlarged lower, left portion of the field shown in Fig. 6.

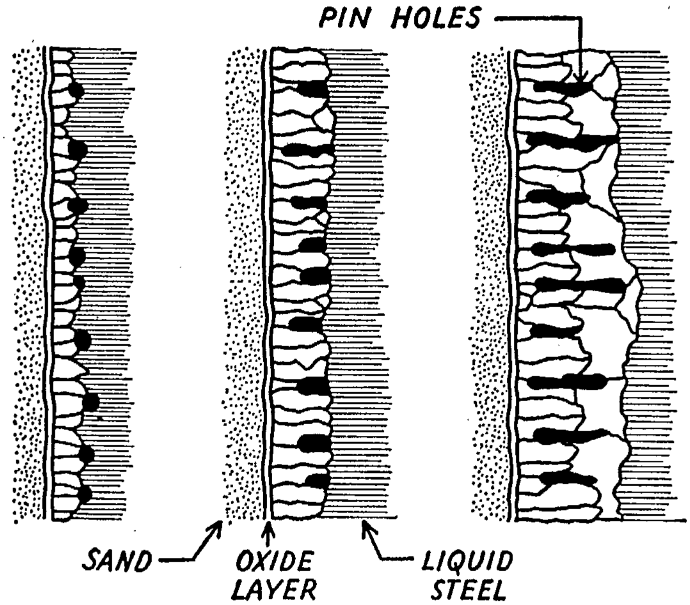


Fig. 8. - Sketch illustrating the origin and development of pinhole porosity.

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