Hydrogen pinholing

Introduction

The pinhole defect is relatively common, particularly in foundries making small to medium section castings in grey, ductile or malleable iron. Usually the pinholing is associated with hydrogen. Less frequently, and then only with chemically bonded sands, pinholing can be associated with nitrogen. These are different defects, with separate causes, which required different corrective actions.

It is therefore very important to identify correctly the cause of the pinholes. This may not be easy even to the expert. If pinholing occurs all the confirmatory tests described below should be carried out. Even then it may be necessary to make some deliberate changes in practice before the cause of nitrogen or hydrogen pinholing can be established with certainty.

Identification

Hydrogen pinholes (Fig. 1) occur just below the surface of the castings as small, more or less round holes up to about 3 mm in diameter having a shiny surface. They are most prevalent in sections thinner than 25 mm which are cast in greensand. This type of defect can occur at almost any sub-surface position, but is most likely to form as distance from the sprue increases (Fig. 2).

Pinholes within a casting are not usually visible after knockout and light shotblasting. They can be seen in a fractured casting (Fig. 3). Most often they are found when machining of a casting takes place (Fig. 4), causing considerable difficulties for both the foundry and the machine shop. The number of pinholes within a casting can range from very few occurring at isolated locations to many affecting most of the sub-surface areas.

Occasionally pinholes may be revealed after heavy shotblasting (Fig. 5). This is most likely to occur when castings have been annealed or heat treated prior to shotblasting.

The occurrence of hydrogen pinholing can be confirmed by a combination of metallographic examination and analysis of the metal. The latter is necessary to differentiate between hydrogen and nitrogen pinholing (see below).

Metallographic examination at low magnification will usually show that the pinholes have a shiny surface (Fig. 6). At higher magnification (Fig. 7) the holes can be seen to be lined with a graphite film and to be free from non-metallic inclusions. The graphite film will not be present in pinholes which may occasionally occur in white or malleable iron. Also it will not be present in grey or ductile irons when the pinhole has been opened up by heavy shotblasting or when the castings have been heat treated.

For reasons given later the occurrence of pinholing due to hydrogen can be confirmed as the most likely cause if, in addition to the above, the analysis of the metal shows that aluminium contents exceed about 0.005 per cent.

The presence of titanium in excess of about 0.04 per cent can add to the effect of aluminium in promoting hydrogen pinholing.

Distinguishing between hydrogen and nitrogen pinholing

The appearance of hydrogen and nitrogen pinholes is similar both visually and in the presence of graphite films revealed during metallographic examination.
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The first distinction which can be made is that nitrogen pinholing is almost universally associated with the use of resin bonded sands and is more likely to occur in ductile iron. It is almost unknown for nitrogen pinholing to occur when only greensand is used to produce a casting. However hydrogen pinholing can occur using green or chemically bonded sands in both grey and ductile irons.

A second guide to distinguishing between hydrogen and nitrogen pinholes is that the latter tend to occur at hot spots even though these hot spots can be at some distance from the chemically bonded sand mould or core face. Nitrogen pinholes may also occur near the junction of a core with a green (clay bonded) sand mould or adjacent to the upper surface of a core.

The best indication of the likelihood of the occurrence of nitrogen pinholing is to determine, by analysis, the nitrogen content of sand. If this exceeds 0.015 per cent then nitrogen is usually the cause of the pinholing. If analysis cannot be carried out the nitrogen content of the sand can be calculated.

To do this, ask the supplier for the nitrogen content of the binder system. Calculate the nitrogen content of the sand mixture from the known percentage additions of binder and catalyst to the mixture. Where reclaimed sand is used add the nitrogen content contributed by this sand to the calculated figure. Again the danger level is 0.15 per cent nitrogen.

Remember that some coatings used for moulds and cores may also contain nitrogen. If this is the case change to coatings of lower nitrogen content.

Causes of hydrogen pinholing

Hydrogen pinhole defects are caused by the liquid cast iron picking up hydrogen from the moisture in the sand mould. This hydrogen then forms small bubbles just under the skin of the casting as the metal begins to solidify. In sand casting practices, pick-up of hydrogen always occurs to some extent. However, there are certain conditions which greatly increase the amount. There are other conditions which encourage the hydrogen that is picked up to form a pinhole. It is when all of these conditions occur simultaneously that hydrogen pinholing such as that shown in Figs. 3–5 can occur.

The principal factor that encourages hydrogen to be picked up is contact between moisture in the mould and liquid metal. This pick up is considerably increased by the presence of a very small quantity of aluminium in the liquid iron. As little as 0.01 per cent aluminium is enough to cause severe outbreaks of hydrogen pinholing. Outbreaks in foundries have been traced to the presence of aluminium contents as low as 0.004 per cent.

The pick-up of hydrogen from moisture, although dominated by the effect of aluminium, is also encouraged by the presence of magnesium in ductile cast irons, high manganese contents, above about 1 per cent, also promote pick up. Effects of aluminium and manganese upon pick up in malleable iron are shown in Fig. 8. Small amounts of titanium in the iron encourage hydrogen pinholes to form, although this element has little effect on the amount of hydrogen picked up. However, neither magnesium, manganese or titanium have been found to produce hydrogen pinhole defects unless some aluminium is also present. To control hydrogen pinholing it is important to recognise the likely sources of aluminium contamination in cast iron, and then to apply measures to prevent such contamination.

Since hydrogen pinholing is a mould/metal reaction there are other controlling factors. These include the composition of the mould, its moisture content which will increase pick up, length of runners which will increase pick up, and in greensands the volatile content which can reduce pick up. It must be stressed that all these factors are subservient to that of aluminium.

Increase in the hydrogen content of the metal through the use of damp launders, damp ladle linings or of inadequately dried coatings will also promote hydrogen pinholing. Sometimes these can be the only identifiable cause.
Prevention of hydrogen pinholing

- Eliminate all sources of aluminium contamination from scrap used in furnace charges.
  Aluminium metal usually enters cast iron as aluminium alloy components or aluminium sheet clippings, mixed with the scrap iron or steel used as part of the furnace charges. An obvious example is pistons in automobile engine blocks. Typical pieces of light alloy collected from cast iron and steel scrap piles are shown in Fig. 9. It has been argued that, as aluminium alloys are non-magnetic, the light alloy parts or sheet clippings will not be picked up by the magnetic cranes. However, almost always the pieces of light alloy are attached to, or entwined with, magnetic scrap iron or steel. Another source is pieces of steel clad in aluminium, such as that shown in Fig. 10. If light alloys are present in the scrap pile there is no doubt that they will also be picked up by the magnet and delivered into the furnace. The solution is to prevent any light alloy from being charged into the furnace. This can be done by specifying purchased scrap quality and inspection of incoming raw materials. Even so some foundries found it economic to offer a bonus to the men working in the furnace charging area, which is based upon the amount of non-ferrous scrap which they recover from the raw materials.

- Control aluminium from ferro alloys.
  The second most common source of aluminium in cast iron results from its presence as a minor element in ferro-alloy additions, particularly ferrosilicon or magnesium ferrosilicon alloys. Most inoculating grades of ferrosilicon require a content of about 1.3–2.0 per cent aluminium in order to develop their full inoculating effects, while magnesium ferrosilicon alloys can contain up to 2.0 per cent aluminium as an impurity. It is impossible to avoid completely these sources of aluminium when making castings that require additions of these alloys to be made. However, it is imperative that the amount of additions used is controlled to the minimum level possible and to use alloys having controlled aluminium contents. For example, large quantities of ferrosilicon containing significant quantities of aluminium are not recommended as part of the furnace charge. Low aluminium grades of ferrosilicon should be used in these circumstances. This applies particularly when melting high steel scrap charges in electric furnaces, where large amounts of silicon may have to be added.

- Completely dry refractory linings in launders and ladles before use.
  Some additions of aluminium to molten iron may be unavoidable. Therefore, it is necessary also to keep out sources of hydrogen. As pick up is due to contact between the liquid metal and moisture, the starting point is to prevent such contact as far as is possible. A particular point is thorough drying after patching or repair of furnace launders, ladles and other metal handling equipment. Coatings applied to moulds and cores should also be thoroughly dried before they are used.

- Control the moisture content of clay bonded sands.
  Keep the moisture content of the moulding sand at a minimum practicable level. Any build-up of dead clay or burnt coaldust which requires the moisture content to be increased in order to maintain mouldability is likely to promote an outbreak of hydrogen pinholing. Build-up of dead clay or burnt coaldust usually has the effect of reducing the shatter index. Effects can be countered by ensuring that there are adequate additions of new sand made to the system. These should usually be in the order to 10 to 15 per cent by weight of metal cast.

- Maintain an adequate level of coaldust or substitute in clay bonded sands.
  Perhaps the most important factor in the control of pinholing in clay bonded sand is the volatile content. It is extremely important that an adequate amount of fresh or 'live' coaldust should be maintained in the moulding sand. Usually for coaldust this should be around 3 per cent, for substitutes around 2 per cent.
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- Avoid long runner systems which increase contact between molten metal and sand.

Since hydrogen pinholing occurs because of the pick-up of hydrogen from the sand mould, it is advisable for the metal to pass over the minimum area of sand when the castings are poured. Thus running systems should be kept as short as possible, and the metal distribution within the mould should be as uniform as possible.

The amount of sand over which the metal is passed, is perhaps of most value when attempting to diagnose the cause of an outbreak of pinhole defects. Fig. 11 shows a possible layout for a multi-cavity mould. If pinholes occur, it is most likely that they will occur in the outer castings if the pinholing is the result of hydrogen pick-up. Whenever possible, it is recommended that the positions of castings in a multi-cavity mould should be identified. This can be of great value in determining causes if an outbreak of pinhole defects occurs.

Even when only one or two castings are made in a mould, the position of pinholes relative to the gate or sprue, can be of help in diagnosing causes. Fig. 12 shows a schematic layout for pouring a flat plate casting such as a brake disc. If conditions likely to promote hydrogen pinhole formation arise, the pinholes are most likely to occur in the areas farthest away from the sprue and the gates.

A practical example of this fact is illustrated in Fig. 13 where severe pinholing has occurred in the area of the castings away from the gates, but no pinholes are present in the areas near to the gate. If pinholes had occurred near to the gate, rather than further away, it would have indicated that they were unlikely to be due to hydrogen pick-up. Other sources of pinholing defects, such as nitrogen, would require investigation.

Summary

Hydrogen pinholing is caused by the pick-up of hydrogen from the moisture in the moulding sand. This hydrogen pick-up reaches pinholing levels when a trace of aluminium is present. Therefore it is imperative to avoid contamination by aluminium as far as possible.

Damp pouring equipment must be avoided. The moisture content of moulds or cores should be kept to a minimum. The volatile matter or live coaldust content of greensands must be maintained at an adequately high level. Long running systems should be avoided.

If an outbreak of pinholing occurs in areas of the casting remote from the sprue there is every likelihood that the cause is hydrogen pick-up from the mould as a result of contamination of the iron with aluminium.
Fig. 1. Likely locations of hydrogen pinholing.

Fig. 2. Pinholes are most likely to occur at increasing distances from the sprue.

Fig. 3. Pinholes in fractured casting.

Fig. 4. Pinholes revealed by machining.

Fig. 5. Heavy shot blasting may "open up" pinholes.
Fig. 6. Fracture showing shiny surface of pinholes.

Fig. 7. Graphite film lining pinhole cavities.

Fig. 8. Effect of aluminium on hydrogen pick-up.

Fig. 9. Typical light alloy scrap.

Fig. 10. Aluminiun ingot scrap.
Fig. 11. Risk of hydrogen pinholing in a multi-cavity mould.

Fig. 12. Probability of pinholing in a brake disc.

Fig. 13. Hydrogen pinholing remote from gates.