Burnt-on sand

Characteristic features

Thin sand crusts firmly adhering to the casting. The defect occurs to a greater extent in the case of thick-walled castings and at high temperatures.

Incidence of the defect

Where there is a heavy-section casting, but also in the proximity of the gate and at high casting temperatures, the moulding sand sinters on the casting in the form of a thin crust due to low thermal resistance. The tendency of the molten metal to penetrate into the sand pores results in the firm adherence of the crust to the surface of the casting. It is difficult to remove, even by shot-blasting, and usually has to be ground off.

Explanations

The high temperature to which the sand is subjected causes sintering of the bentonite and silicate components. In addition, the always present iron oxides combine with the low-melting-point silicates to form iron silicates, thereby further reducing the sinter point of the sand. Sintering and melting of the impurities in the moulding sand enable the molten iron to penetrate even faster, these layers then frequently and firmly adhering to the casting surface.

Possible causes

Clay-bonded sand
- Lustrous carbon content too low
- Proportion of low-melting-point substances too high
- Oolitization too high

Moulding plant
- Uneven mould compaction

Gating and pouring practice
- Uneven distribution of inflowing metal with resultant overheating
- Temperature of liquid metal too high

Remedies

Clay-bonded sand
- Increase proportion of lustrous carbon producer. This increases the amount of coke as well as the amount of lustrous carbon, which then results in positive separation between mould and metal.
- Use purer silica sands or, if necessary, add new sand. Reduce dust content. If necessary, reduce the amount of bentonite.
- Reduce oolitization by adding new sand.

Moulding plant
- Ensure uniform compaction. If necessary, increase heat removal from the moulds.

Gating and pouring practice
- Even out incoming metal flow
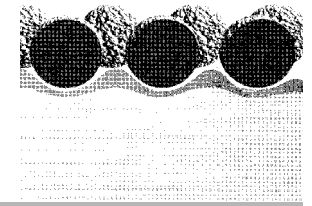- Reduce pouring rate
- Reduce liquid metal temperature

Fig. 1:   Sand grains on the surface of a grey iron casting with insufficient lustrous carbon.
           Scale: 10 mm ≙ 0.08 mm

Fig. 2:   Thin-wall grey iron casting with closely adhering sand layer.
           Scale: 10 mm ≙ 8.1 mm

Background information

Adhering sand layers primarily form when the lustrous carbon-producing capacity of the moulding sand is too low. With grey iron castings, the lustrous carbon content in the sand should lie between 0.2 and 0.6 %, according to other authors between 0.2 and 0.4 % .[1] Due to the difficulty in precisely determining the lustrous carbon in the sand, the "active carbon content" is measured and should be between 0.35 and 0.65 %.

If sand adherence is experienced, this can be eliminated either by using a higher proportion of or a more "active" lustrous carbon producer.

Improved coke formation will likewise reduce the formation of adhering crusts, but not as much as increasing lustrous carbon production.

It is important to limit impurities in the moulding sand. Silicates and oxides can lead to excess consumption of lustrous carbon producers due to oxidation.[2] Lowering the sinter point of the sand also increases the risk of burning-on, with simultaneous penetration of metal into the adhering layer.

Likewise, intensified burning of sand onto grey iron castings has been observed with the use of more highly oolitized moulding sands. It is therefore recommended to add an appropriate amount of new sand to that in circulation. According to our previous experience, the added amount should not significantly exceed 100 kg of new sand per t of molten iron.

Russian authors report that, when pouring molten steel into sodium silicate bonded moulds, burning-on is drastically reduced where the surface tension is increased through the use of additives.

Boosting the AFS number by using finer new sands similarly reduces adherence of sintered crusts because the casting surface is smoother.

The moulds should be well and uniformly compacted. There is a greater risk of metal penetration at locations where compaction is low, and thus of the formation of adhering crusts.

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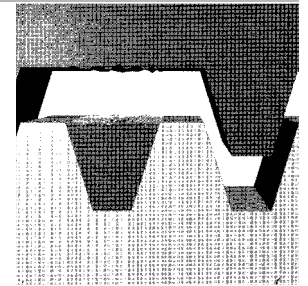
Fig. 3:   Grey iron casting after a cod has broken off in the mould and remained in the pattern.
Scale: 10 mm ≙ 30 mm

Fig. 4:   Grey iron casting. Broken off sand edges adhered to the pattern.
Scale: 10 mm ≙ 8.1 mm

Cods and edge disintegration

Assistance for decisions → P. 126
Sand control → P. 176

Characteristic features

Cracking and breaking of sand cods, iron fins penetrating into cracks. In the case of breaking of complete parts of the mould, inclusion of the cod in the casting.

Incidence of the defect

Breaking of cods occurs with too brittle or with highly compacted sands. The defect is particularly evident with deep cods or where their depth / width ratio is unfavourable. The pattern design has a considerable effect on this defect.

Explanations

Cod breakage occurs when its adhesion to the pattern is greater than its tensile strength. It most frequently arises when the mould is being stripped from the pattern and where the moulding sand has insufficient plasticity.

Possible causes

Moulding plant
- Uneven stripping of the mould, excessive leverage on the cod
- Tapers on pattern and mould are too small
- Formation of sand bridges through uneven filling of the sand
- Compaction too high, thus too much mould / pattern adhesion

Clay-bonded sand
- Insufficient plasticity
- High dust content in the sand
- Sand too hot
- Insufficient bentonite-binding capability
- Too much clustering

Remedies

Moulding plant
- Improve stripping from pattern; the mould is often not evenly stripped
- Distribute sand evenly in the flask
- Avoid excessive local compaction and thus too much mould / pattern adhesion
- Increase taper on pattern and mould
- Reduce compacting pressure in the moulding plant
- Use a release agent

Clay-bonded sand

- Improve plasticity of the sand. This can be done by increasing the bentonite content whilst retaining the same compactability, or by raising the compactability.
- Improve development of the moulding sand. It is important to pre-moisturize used sand at an early stage (min. 2 % water with approx. 8 % bentonite in the sand).
- Use carbon carriers containing process carbon, e.g. Antrapur and Priocarbon. Use of bentonites containing process carbon, e.g. Quickbond, very much accelerates development.
- Improve flowability of the sand during compaction. This can also be achieved by using products containing process carbon.
- Reduce proportion of inert dust. The moulding sands will otherwise lose their plasticity. Use bentonite with a high montmorillonite content and restrict recirculation of dust.
- Reduce the proportion of clusters. If necessary, use a sand disintegrator; otherwise, limit the total amount of fines (bentonite + inert content).

Background information

Cod breakage is most frequently caused by defects in the moulding plant. When it occurs, the first thing to check is the separation between mould and pattern plate. The mould must be stripped without tilting. Especially with deep cods, even 0.2 mm will cause an over-critical tilt, thus leading to the cod breaking off. When assembling the cope and drag halves, it is important that the locating pins are not worn and that the mould halves can be fitted together without displacement.

When cods do break off, their taper should be checked and, if necessary, altered.

It is essential to uniformly fill the mould areas and cods with moulding sand. The sand must be aerated and introduced with as few clusters as possible, otherwise sand bridges can form across recesses in the pattern, thus making it difficult to fully fill the mould. The correct matching of sand quality to moulding plant with regard to flowability and plasticity has a great influence on the occurrence of defects. With excessive compaction, the mould / pattern adhesion of the cod increases to a greater extent than the cod tensile strength.[1, 2] Increasing the flowability of the sand contributes to maintaining low compacting pressures.

The use of products containing process carbon assists in improving flowability.

Release agents considerably affect the stripping characteristics of the cod.[3] In his work, Levelink describes the influences that the pattern material and also the sand and pattern temperatures have on the adhesion forces. The properties of clay-bonded moulding sand also have a great influence on the breakage of cods and edges. The sand plasticity should be kept as high as possible.[3, 4]

Plasticity of circulating sands is very much dependent on the degree of mulling, and increases with an increase in the pre-moisturizing of used sand. Fig. 5 shows this by the example of bentonite-bonded circulating sands. Even when mixed five times longer with the same amount of water, a thoroughly dried-out sand will not achieve the same plasticity as a moist circulating sand. The sand only reaches a comparable plasticity when it has been stored for a period of 3 hours after pre-moisturizing with 1.5 % water. In our opinion, the used-sand moisture content should be between 2 and 3 %. The reduced flowability of these sands must be taken into account in the design of storage and conveying systems.
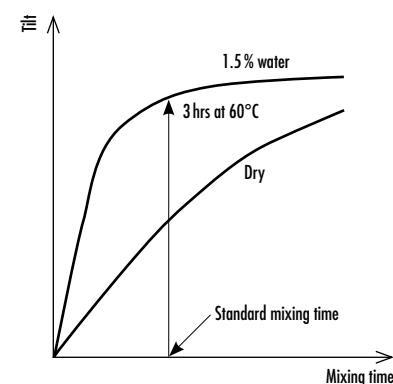

Fig. 5

When circulating sands have insufficient plasticity, their green tensile strength should be measured after sufficient storage time. In the event of too high a proportion of fine inert dust, the sand becomes brittle.[5] In practice, it has been shown that moulding sand becomes considerably more brittle when the inert fine dust content exceeds 3 %.

Dust extraction and possibly bentonite quality must be matched to the requirement for low proportions of inert dust. The use of bentonite with a high montmorillonite content can frequently boost the green tensile strength to such an extent that cods no longer break off and there is no edge crumbling.

Boenisch introduces the concept of a ductility limit as a measure for plasticity[5] and shows that raising the montmorillonite content in the bentonite considerably increases plasticity, thereby reducing the risk of cod breakage. In the same paper he points out that a high admission of used core sand or new sand drastically reduces plasticity without reducing green compression strength. We have already pointed out the need for sufficient development of bentonite. The temperature of the moulding sand also has a great influence. With temperatures in excess of 40°C, sand embrittlement is likely to be a constant problem. A 10 to 20 % reduction in green tensile strength already occurs at sand temperatures of 40°C. Hot sands quickly lose their surface moisture, resulting in embrittlement. These phenomena have been studied by Pohl.[6]

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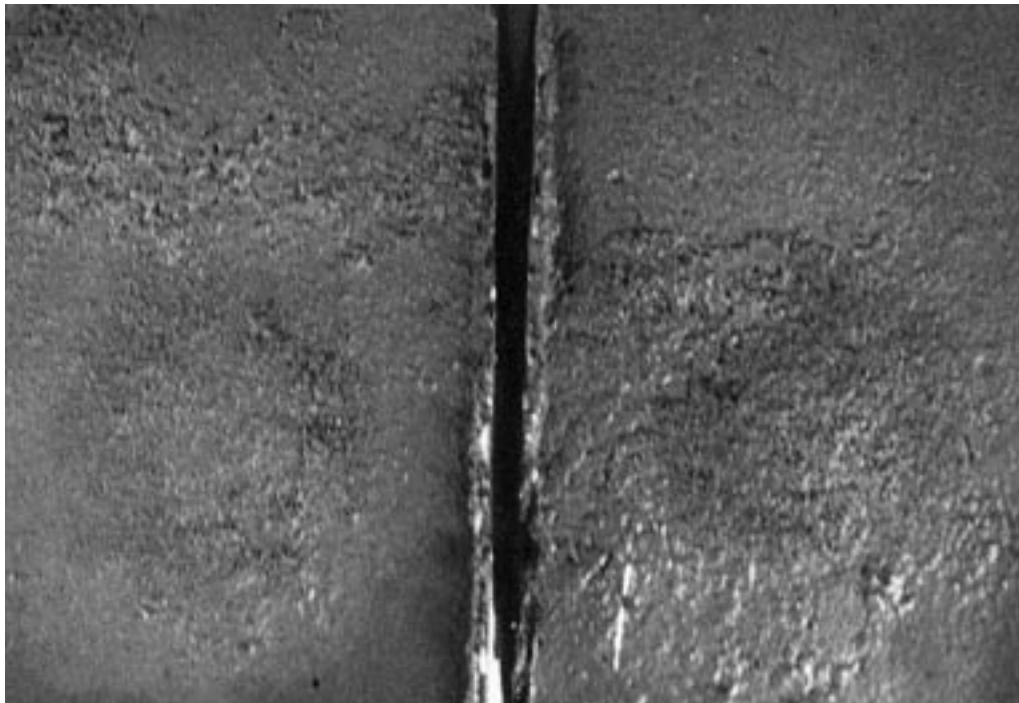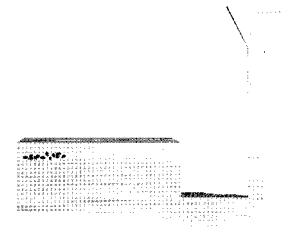   Giesserei 85, Heft 1, 1998 P. 87–90

Fig. 6:   Sample grey iron casting for testing of erosion with a clay-bonded moulding sand.
            Scale: 10 mm ≙ 10 mm

Erosion

Assistance for decisions → P. 128
Sand control → P. 177

Characteristic features

Sand erosion principally occurs in the proximity of the gate and is frequently combined with slag inclusions. Thickening of the casting occurs in this area.

Incidence of the defect

Where the sand grains are insufficiently bonded together by bentonite, the particles are loosened by the metal flow. The defect occurs largely where moulds have dried out quickly (high sand temperatures), or have been poorly prepared and contain too little water or bentonite. The defect is more frequently observed in the proximity of the gate and where a long pouring time has been applied.

Explanations

Erosion defects occur as a result of moisture loss where moulds have been standing for long periods without pouring. The defect has arisen with increasing frequency since the introduction of high-pressure moulding plants, as sands of lower compactability are used.

The binder is not able to hold the silica grains in the mould surface. They are flushed out and dispersed to remote regions of the casting.

Possible causes

Clay-bonded sand

- Content of active bentonite too low
- Insufficient cohesion of the bentonite. Can be caused by inadequate bentonite quality or insufficient development of the bentonite
- Too high a proportion of inert dust to be bonded in the sand
- Sand temperature too high. The sand dries out and loses its cohesion
- Sand too coarse, therefore too small a contact surface. Bonding of the grains in the mould surface is insufficient
- Lustrous carbon content in the moulding sand too low. Molten metal wets the sand grains and detaches them from the mould surface
- Salt content in moulding sand too high. The binding capability of the bentonite is reduced

Moulding plant

- Low compaction of mould parts

Gating and pouring practice

- Pouring rate too high. Parts of mould become too hot and are eroded.
- Volume of metal flowing through too great. Severe local overheating of the mould takes place

Remedies

Clay-bonded sand

- Increase the amount of bentonite.
- Check that quality of the bentonite is in accordance with VDG (Verein Deutscher Giessereifachleute) Data Sheet P 69. If possible, use bentonite with lower proportion of inert material.
- Improve development of bentonite. Increase moisture, increase mixing times. If necessary, introduce pre-moisturization of used sand.
- Lustrous carbon producers with process carbon and, above all, specially prepared bentonite / process carbon systems such as Quickbond, improve development of the sand.
- Reduce sand temperature to below 40°C. Improve cooling of sand. If necessary, improve moisturization of used sand.
- Use finer sand.
- Increase lustrous carbon carrier in moulding sand or change over to more active materials.
- Increase addition of new sand when the salt content in the sand is too high. If necessary, introduce partial desalination of water.

Moulding plant

- Improve and homogenize compaction in mould. Endeavour to achieve more homogeneous mould filling.
- Carbon carriers containing process carbon and bentonite improve flowability during compaction.

Gating and pouring practice

- Reduce pouring rate
- Modify the gating system to achieve uniform distribution of heat in the sand.

Background information

The tendency to erosion in bentonite-bonded moulding sand depends largely on the proportion and quality of the bonding agent, the development of the bentonite and the tendency of the moulding sand to dry out.

If the bentonite content decreases while the compactability of the moulding sand remains the same, susceptibility to erosion increases. The tendency of the sand grains to be flushed out from the mould surface depends on the cohesive forces, which can be determined by measuring the green tensile strength. Bentonites with a higher montmorillonite content have a lower inert material content. This results in a higher ratio of green tensile strength per percentage of bentonite in the moulding sand, which will reduce the risk of erosion. Erosion defects are frequently caused by using sands with low compactability.[1] Even slight loss of water vapour will lead to insufficient bonding of the silica grains in the mould surface. In cases of erosion, Levelink recommends that the clay content be increased and finer sands be used.[1] According to measurements recorded by IKO, the use of finer sands leads to a considerable reduction in water vapour loss at the mould surface, thus counteracting the loss of cohesion. The use of carbon carriers containing process carbon and bentonites has a similar effect. A higher and more uniform packing density for the sand grains is achieved during moulding. Water evaporation is considerably reduced.
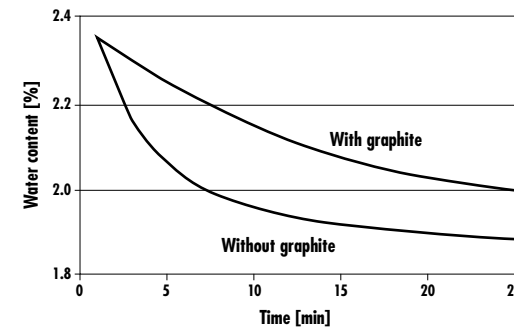
Fig. 7

However, the bonding of the silica grains in the mould is also improved when using finer sand.

The temperature of the moulding sand has a considerable influence on the mould surfaces drying out and the consequent risk of erosion. With ready-to-use sands, the temperature should not exceed 40°C. The preparation of a moulding sand should be as good as possible, as water evaporation is then minimal. The degree of mulling is defined according to Levelink.[2]

When using bentonites containing process carbon, the moulding sand is developed more quickly. Water evaporation and thus the tendency to erosion can also be reduced in this way.[3] Higher lustrous carbon-producing materials reduce the risk of erosion through the formation of separating lustrous carbon layers.

Under-compacted regions of the mould are susceptible to erosion defects. Levelink has highlighted the decline in the tendency to erosion with greater mould hardness.[1]

Better anchoring of the sand grains and reduction in water evaporation are the reasons for the reduction in defects.

Finally, it should also be noted that the design of the gating system is important for the incidence of erosion, particularly where it occurs in the gate or near to it. Excessive quantities of molten metal should not be allowed to flow across any one part of the mould. Impingement of inflowing metal onto parts of the mould should also be avoided.

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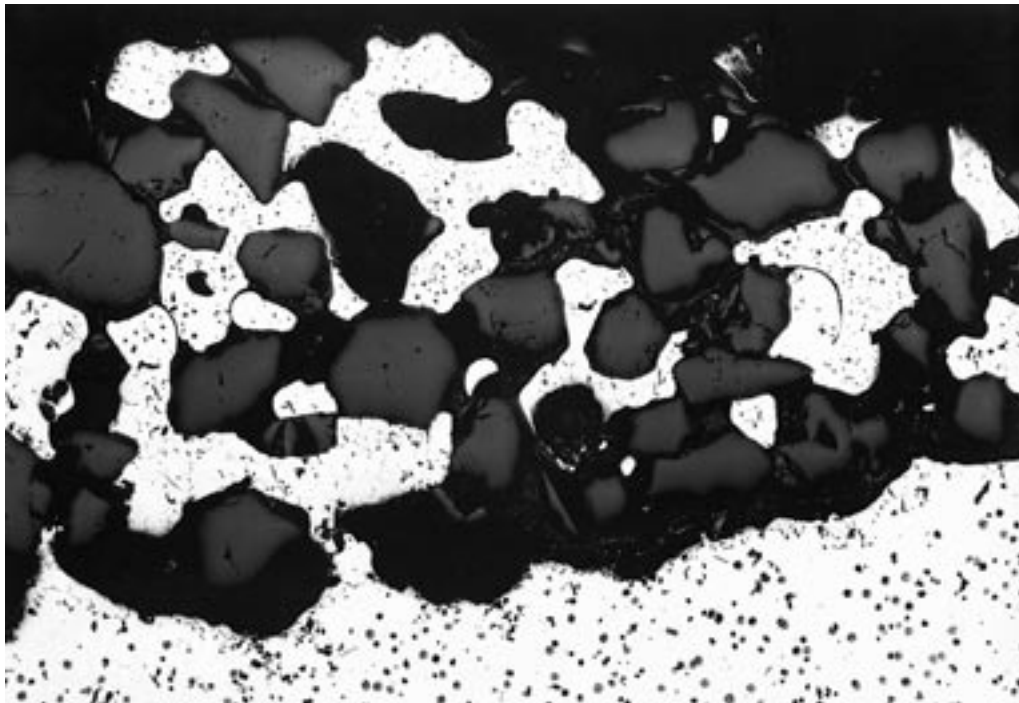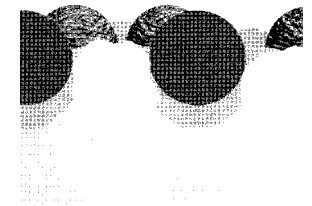   Trans. Amer. Foundrym. Soc. 81, 1973, P. 49−58

Fig. 8:   Micrograph of a penetrated layer of an SG iron casting. Despite high surface tension, the melt has been forced into the sand pores. Scale: 10 mm ≙ 0.3 mm

Fig. 9:   Large-area penetration in regions of fast inflowing metal. Grey iron casting.
Scale: 10 mm ≙ 13 mm

Explosive penetration

Assistance for decisions → P. 131
Sand control → P. 177

Characteristic features

Large-area penetration occurs in regions of the mould which have been filled with metal too quickly.

Incidence of the defect

With molten metal flowing into a sand mould, explosive water evaporation often occurs at positions where streams of metal flow together or flow faster. This "water vapour explosion" imparts a dynamic jolt to the metal which forces it into the sand pores over a large area. In contrast to pure penetration, this phenomenon does not just occur at under-compacted areas or hot spots. Its incidence is closely coupled with the path taken by the flowing metal and is often observed in the last part of the mould cavity to be filled. A uniformly thick penetrative crust often forms.

Explanations

The defect has occurred more frequently with the introduction of high-pressure moulding and, in particular, with the introduction of core-making processes which have led to a high degree of re-plenishment of the moulding sand. Levelink[1] was the first to investigate these phenomena and found the reason to be the explosive expansion of water which has condensed on the mould surface. A fast flow rate of molten metal causes the condensed water to evaporate explosively when the metal comes into contact with it. The resultant pressure increase then forces the molten metal into the sand pores.

Possible causes

Clay-bonded sand
- Moisture levels too high, above all "free" water in the moulding sand.
- Insufficient mulling of the moulding sand. The water is quickly released.
- Proportion of inert dust too high, thereby binding in too much water.
- Amounts of binder too high and thus too much water.
- Sand grains too coarse. Slight pressure increase through evaporating water leads to penetration.
- Too much water bound in due to lustrous carbon producer and its residues.

Moulding plant
- Moulds too highly compacted.
- Unevenly compacted moulds with over-compacted areas.

Gating and pouring practice
- Pouring rate too high. Metal flowing over areas with condensed water. Metal streams running together too quickly.
- Incomplete venting of mould and core gases from the mould cavity.

Fig. 10:   Grey iron casting. Large-area penetration over the complete grate.
              Scale: 10 mm ≙ 16 mm

Fig. 11:   Grey iron casting. Heavy penetration all over the lower part.
              Scale: 10 mm ≙ 25 mm

Remedies

Clay-bonded sand

- Reduce water content through use of high-quality bentonite with high thermal stability and high montmorillonite content.
- Reduce compactability.
- Improve degree of mulling by pre-moisturizing used sand, by accelerating water absorption of bentonite, by increasing mixing times.
- Reduce inert dust content through use of high-quality bentonite. If necessary, restrict dust recirculation.
- Reduce bentonite content. Use more highly active bentonite with higher montmorillonite content.
- Reduce sand grain size. Use finer core sands or, from time to time, add fine new sand to circulating sand.
- Use more active lustrous carbon producers. Reduce amount of lustrous carbon producers and coke.

Moulding plant

- Homogenize mould compaction and reduce compacting pressures.
- Endeavour to achieve more uniform sand filling.

Gating and pouring practice

- Reduce pouring rate by modifying gating system. Reduce rate of mould filling.
- Spray oil into sections at risk, thereby avoiding water condensation at these points.
- Provide vents to improve removal of gases containing water vapour.

Background information

The moulding sand has a very strong influence on the occurrence of explosive penetrations. Essentially, the compactability of the sand should be as low as possible. However, the occurrence of condensed water largely depends on the amount of free water. For this reason, optimum mulling of the moulding sand is required. In addition, all additives should be examined and replaced by more "active" substances as appropriate. It has been operationally proved that the defect can be avoided merely by using bentonite with a high montmorillonite content, since the inert fines content and thus the water requirement is reduced. The defect is greatly affected by the grain size of the sand. Where a very coarse circulating sand is used, the defect occurs more frequently. It disappears when the sand grain size is reduced by the addition of finer new sand. We recommend that the AFS number be maintained above 60.

When explosive penetration occurs, the lustrous carbon carrier is often replaced by materials that produce less coke and have a greater capacity for forming lustrous carbon. As a result, the water requirement is also reduced.

Hofmann has found evidence that sands with a degree of oolitization in excess of 15 % do not have a tendency to cause explosion defects.[2]

Over-compacted moulds more often show defects resulting from explosive penetration. Levelink highlighted this interrelationship in an authoritative paper.[1] Not only the moulding sand but also the hardness of the mould should be checked when these defects occur and, if necessary, the compacting pressure reduced. Levelink cites raising the pouring temperature[3] as a means of avoiding this defect. Optimizing the gating system appears to be of greater importance. Incidences of explosive penetration can be avoided by employing tangential gating of the mould, with better distribution and laminar metal flow.

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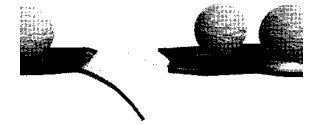
Fig. 12:   Grey iron housing. Area of very large lustrous carbon inclusions in the top part of the casting.
             Scale: 10 mm ≙ 33 mm

Fig. 13:   Grey iron housing. Area of very large lustrous carbon inclusions in the top part of the casting.
             Puckered lustrous carbon formation. Scale: 10 mm ≙ 8 mm

Lustrous carbon inclusions

Assistance for decisions → P. 133
Sand control → P. 178

Characteristic features

The formation of flow marks, inclusions, metal separation through unwetted carbon films, these often being invisible because they can lie perpendicular to the wall of the casting.

Incidence of the defect

Lustrous carbon inclusions occur where there is a surplus of lustrous carbon producers in the moulding and core sand. They are often deposited in regions of the casting in which greater turbulence occurs due to differences in density. In the case of spheroidal graphite (SG) cast iron, they occur more frequently in conjunction with oxide and slag defects.

Explanations

Lustrous carbon forms on inert surfaces through thermal decomposition of hydrocarbon-bearing gases in reducing atmospheres above 650°C.

Lustrous carbon is deposited as a film on the silica grains of the mould. Relatively thick layers of lustrous carbon film can result from the gas pressure which develops, particularly when deposited on core sections.

Possible causes

Resin-bonded sand
- Lustrous carbon producing capacity of the core binder too high.
- Insufficient venting of core gases.

Clay-bonded sand
- Excessive formation of lustrous carbon in the moulding sand.
- Excessive or rapid release of lustrous carbon from the carbon carrier.

Moulding plant
- Gas permeability of the mould surface too low

Gating and pouring practice
- Too much turbulence, leading to inclusion of lustrous carbon
- Pouring temperature too low

The different thermal expansions of the silica and the lustrous carbon deposit can also give rise to the detachment of thicker films.

Remedies

Resin-bonded sand

- Reduce amount of cold-box binder; if necessary, change over to binder with lower lustrous carbon producing capacity.
- Warm up cold-box cores in order to reduce the proportion of solvent.
- Improve the venting of core gases. Check the core print for dressing residues, use coarser sand.
- Add oxidation agent to the cores.
- Dress cores, apply thicker layer of coating.

Clay-bonded sand

- Reduce lustrous carbon production in the moulding sand either by decreasing the amount of additive or by using other carbon carriers with lower lustrous carbon producing capacity and slower release of gases.
- Improve gas permeability of moulding material.

Moulding plant

- Reduce compacting pressure in the moulding plant.
- Increase gas permeability of the mould.

Gating and pouring practice

- Avoid turbulence, ensure laminar flow of the metal.
- Increase pouring temperature.

Background information

The amount of undecomposed lustrous carbon producer in the moulding sand is crucial to the incidence of the defect. Because the oxidation processes caused by the water combined in the bentonite preclude determination of lustrous carbon production in the sand by established methods, one determines the "active carbon". The normal maximum amount should not exceed 0.6 %.

Beckerer and Spatz [1] examined the mechanism by which lustrous carbon layers are produced. Further experiments on the pyrolitic behaviour of organic substances were carried out by Wörmann and others.[2] They found clear correlations between chemical structure and the formation of lustrous carbon. The highest percentage yield of lustrous carbon was obtained by pyrolizing anthracene. They demonstrated that, through the use of defined substances, it is possible to establish the relationship between lustrous carbon production and coke formation.

In their studies, Bindernagel and others[3] had already highlighted defects due to lustrous carbon inclusion. They recommend using the lowest possible amount of lustrous carbon producer and believe that a lustrous carbon producing capacity of 0.4 % in the moulding sand is sufficient.

In addition to lustrous carbon, soot can also be deposited during thermal decomposition. The conditions which lead to increased soot formation have not yet been exhaustively investigated. Deposited soots do not have a pronounced separating effect on the boundary between the metal and the sand mould. Due to its high specific surface, soot is quickly dissolved by molten metal.

Increasing the gas permeability of the moulding sand reduces the risk of lustrous carbon inclusions. However, to achieve the same degree of surface finish, a greater proportion of lustrous carbon producer must be employed. The influence of fines and the quantity of lustrous carbon producer is described in the concluding report of AIF research project 5405.[4, 5]

Considerable quantities of lustrous carbon can be produced from the cores (primarily Croning and cold-box cores). The venting of the core gases is therefore very important. The drying of such cores has been carried out at various times to avoid inclusions of lustrous carbon.

Core sand flowing into the bentonite-bonded sand can also significantly increase the formation of lustrous carbon. This must be particularly taken into consideration where cold-box cores are used.

Coarse sands are used for cold-box cores, which may require dressing of the mould parts. Naro [6] recommends a very thick application of dressing with a low proportion of volatile components. In Germany, the use of water-based dressings to seal cores is becoming increasingly popular. It is just as important to examine whether the pouring temperature can be raised where lustrous carbon inclusions occur. Naro [6] has found that lustrous carbon inclusions decrease with an increase in pouring temperature. Rapid pouring also reduces the risk of inclusion, provided laminar flow takes place. Where turbulence occurs, graphite films can become detached from the silica surface and lead to inclusions.

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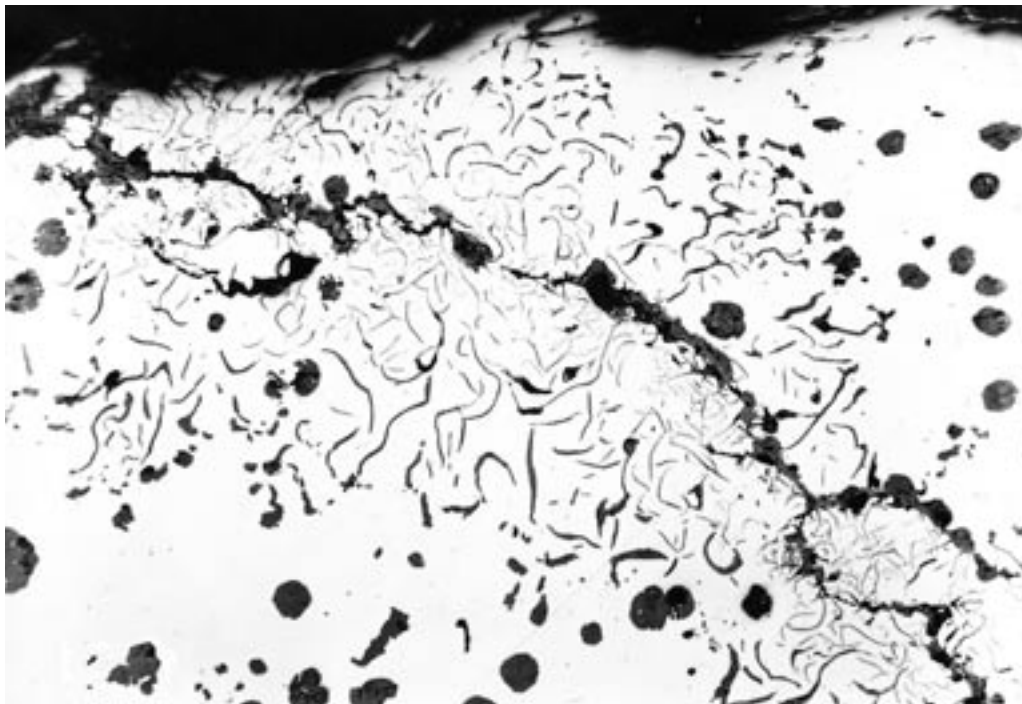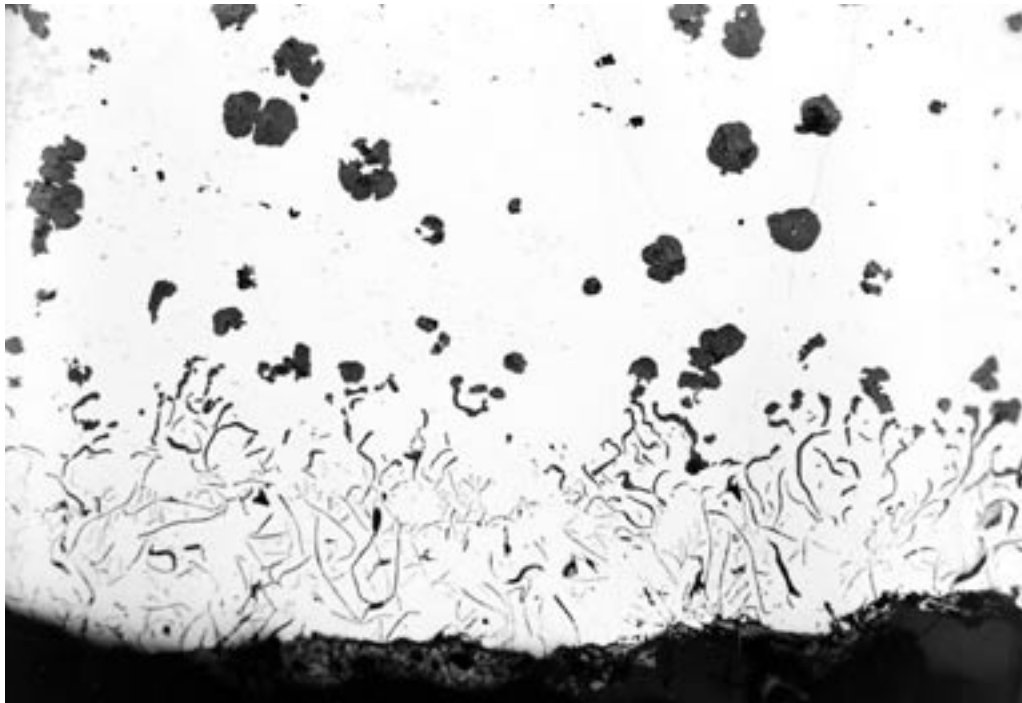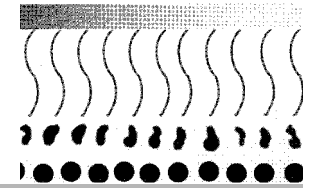   Trans. Amer. Foundrym. Soc. 85, 1977, P. 65−74

Fig. 14:　Surface of a casting of SG iron with a 0.3 mm wide zone containing flake graphite.
　　　　　Scale: 10 mm ≙ 0.07 mm

Fig. 15:　Linear shaped slag inclusion in an SG iron casting. Slag inclusion surrounded by a flake graphite seam.
　　　　　Scale: 10 mm ≙ 0.07 mm

Graphite degeneration

Characteristic features

Degenerated graphite layer deposited on the surface of the spheroidal graphite (SG) cast iron as a flake graphite seam.

Incidence of the defect

Depending on the casting wall thickness and rate of cooling, a 0.2 to 1 mm thick degenerated seam of flake graphite can occur on SG iron castings. This seam then blends smoothly into the structure of the spheroidal graphite.

The defect can occur with any moulding technique and is principally dependent on the sulphur content in the mould and the supply of oxygen at the mould surface. The mould regions which are most at risk are those furthest away from the gate.

The flakes which have formed on the casting surface can undermine its fatigue strength when it is subjected to alternating stresses.

Causes

Where a degenerated graphite layer of this type forms on the surface of the casting, oxygen from the mould cavity or sulphur from the moulding material reacts with magnesium so that the residual magnesium content is no longer available for the formation of graphite spheroids, and therefore only flakes form.

Magnesium consumption at the surface of the mould can be due to an excessive supply of oxygen (V-process, shell-moulding method) or to sulphur from the carbon carrier (e.g. bitumen) or p-toluene sulphonic acid as the hardener used in cold-resin moulding.

It appears that the sulphur can dissipate before solidification begins in the molten metal, without there being sufficient time for new spheroidizing elements to reach the surface by diffusion from adjacent metal layers.

Background information

Degenerated graphite seams often occur in SG iron castings. They can project below the surface of the casting by up to 1 mm and are therefore normally removed when machining the metal. However, the flake graphite seam remains in unmachined sections and has the effect of a notch on castings which are subjected to fatigue stresses.

This degeneration is generally ignored on large castings with a greater wall thickness. The defect has been investigated by numerous researchers and foundries. The causes are now clearly explained. The sulphur in the moulding material is of particular significance here. It migrates into the molten metal and consumes the dissolved magnesium as well as the cerium mischmetal through the formation of magnesium sulphide, MgS. The amount of Mg (< 0.015 %) remaining on the surface of the moulding material is insufficient for the formation of nodular graphite and, when solidifying, flake graphite crystallizes out in the form of an approx. 0.2 – 1 mm thick layer. This is referred to as a degenerated-graphite surface.

Large amounts of oxygen present in the air can also lead to the formation of MgO, and the metallic Mg is thus no longer available for the production of nodular graphite. The sulphur content in the moulding material comes principally from sulphur-rich lustrous carbon producers or, in the case of cold-setting resin moulding, from p-toluene sulphonic acid.

Bauer[1] carried out investigations into the breakdown of nodular graphite formation in the surface layer of SG iron when casting in a furan resin-bonded mould hardened with p-toluene sulphonic acid. He suggests keeping the quantity of p-toluene sulphonic acid as low as possible and even blending this with phosphoric acid. He draws attention to the accumulating sulphur content in regenerated circulating sands.

The limits depend on the wall thickness:

Up to 25 mm thick	< 0.15 % sulphur in the sand
Up to 75 mm thick	approx. 0.07 % sulphur in the sand

Dressing has a positive effect; however, the dressing must be of a particularly high density. Dressings with a CaO/MgO/talc composition are regarded as particularly effective.

Martin and Karsay[2] have studied the local precipitation of flake graphite due to a reaction between SG cast iron and a number of harmful components in the moulding material. They also arrive at the conclusion that certain dressings can prevent the degeneration. Barton[3] attributes the quality and depth of the non-nodular graphite to the residual magnesium content in the iron, the flow characteristics of the metal in the mould, the cross-section of the casting and the conditioning of the moulding sand. Magnesium may then be lost due to reaction with the air within the mould and with the sulphur contained in the moulding sand. He suggests that the proportion of sulphur in the lustrous carbon producer be limited to 1 %.

For cold-setting resin and regenerated used sand, a sulphur content of 0.15 % should not be exceeded. Increasing the magnesium content alone would be insufficient to compensate for high sulphur contents.

Barnabe[4] also states a limit of 0.15 % for the sulphur content. In addition, he cites the proportion of MgS as the influencing parameter.

Voroncov and colleagues[5] have examined the influence of the pouring temperature. According to their findings, it should be possible to greatly reduce degeneration at low pouring temperatures (1330 – 1360 °C). Here, suitable dressings based on FeSi or Al for deoxidation are suggested.

Dunks[6] reports on the influence of the moulding materials and mould dressings on graphite structure in the production of SG cast iron. Sodium silicate-bonded sands and bismuth dressings are said to promote degeneration.

Golovan[7] provides evidence that, for a fatigue-stressed crankshaft cast in a shell mould, the depth of the degenerated layer has an effect on the fatigue limit. The cooling rate, casting temperature and residual magnesium content are further influencing factors.

Here it is discussed for the first time that the degenerated zone can arise not only through oxidizing gases but also through the reduction of silica sand in accordance with the reaction:

$$SiO_2 + 2\,Mg \rightarrow Si + 2\,MgO$$
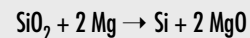
Testing

Y2 wedge test bars as used by Bauer[1] and Berndt[6] in experiments are particularly useful for testing for degenerated graphite zones.

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Fig. 16:   Micrograph of a crack in a grey iron housing caused by the formation of nitrogen molecules.
            The dendritic structure of the iron is a characteristic feature. Scale: 10 mm ≙ 16 mm

Fissure defects

Characteristic features

Mostly narrow crack-like cavities which often run perpendicular to the casting surface. The interior of the cavity is predominantly dendritic. The surface of the cracks is not as shiny as that found with hydrogen pinholes. The defect can be several millimetres wide.

Where there is an extremely high nitrogen content, the cavities become round and the surface of the blowhole smooth. There are no inclusions found in the nitrogen defects.

Incidence of the defect

The up to 2 cm deep crack-like cavities, mostly perpendicular to the surface, frequently have dendritic structures in the surface of the cavity. The defect can occur at mould surfaces and edges as well as at core surfaces. The fissures arise through the precipitation of nitrogen during solidification, simultaneous precipitation of hydrogen intensifying the defect even further.

Nitrogen defects can be distributed over a larger area of the casting than blowholes. A casting with a thicker wall is more likely to show this defect than a casting with a thinner wall.

Explanations

Molten cast iron containing a high proportion of scrap steel has a high nitrogen content, which may be in excess of 100 ppm. The likelihood of fissure defects has grown with the increased use of scrap steel. The risk of gas defects has also increased through the use of nitrogen-containing binders (mould and core binders) and carburizing compounds.

Possible causes

Metallurgical
  - Nitrogen content in the melt too high.
  - Titanium content low relative to comparatively high nitrogen content.
  - Carbon equivalent low relative to comparatively high nitrogen content.

Resin-bonded sand
  - High nitrogen content in the core binder or too much binder
  - High formation of gas and poor core venting.

Clay-bonded sand
  - High moisture content in the sand and consequently high water absorption by the melt.
  - High nitrogen content in the sand resulting from incoming core sand or lustrous carbon producer.

Fig. 17:   Cracks in a grey iron ring due to formation of nitrogen molecules.
Scale: 10 mm ≙ 4 mm

Remedies

Metallurgical
- Reduce proportion of steel in the charge makeup. Reduce nitrogen content to 100 ppm.
- Bind nitrogen content in the melt through the addition of titanium.
- Increase the carbon equivalent.

Resin-bonded sand
- Use binder with lower nitrogen content.
- Use binder with slower release of gas; if possible, use binders with less gas.
- Add iron oxides.

Clay-bonded sand
- Reduce moisture content through better sand development, reduced addition of bentonite and smaller amounts of inert dust.
- Reduce nitrogen content in the sand. If necessary, reduce lustrous carbon carrier content or use low-nitrogen carbon carrier.
- If necessary, reduce nitrogen content in the inflowing core sand.

Gating and pouring practice
- Shorten the pouring channels in order to reduce gas pick-up.
- Increase pouring temperature and, if necessary, also the pouring rate.

Background information

Fissure defects are principally attributed to the nitrogen content in the iron melt being too high. Reference works state that the limit for grey iron and SG cast iron is 100 ppm.[1, 2] Below this value, gas precipitation can be excluded.

A high proportion of scrap steel in the charge make-up will increase the nitrogen content of the melt. In a test foundry, the following values were determined[3] in a cupola iron:

Proportion of steel [%]	Nitrogen content [ppm]
20	110
80	150
100	170

The solubility of nitrogen in iron can be influenced by various alloying elements. Vanadium and chromium increase solubility, silicon and carbon reduce it.

Nitrogen-containing carburizing compounds can also lead to fissure defects. Reports on such defects have already been presented.[4] It is possible to combat these defects by adding titanium or aluminium to the iron melt. However, the risk of increased water absorption through the use of these substances should be considered.

Absorption of nitrogen by the iron melt from the air is unlikely, due to the high bonding energy of the nitrogen molecule. The absorption of nitrogen from mould binders is far more significant. Cold-setting and hot-setting resin binders frequently contain proportions of urea resin with a high nitrogen content. The Croning technique (shell process) uses hexamethylene tetramine as the hardener. The isocyanate components of the cold-box hardener also contain nitrogen. The occurrence of defects can be suppressed by the addition of iron oxide.

Nitrogen is readily absorbed from many nitrogen compounds. In an experiment, increasing quantities of Na_3 $[Fe(Cn)_6]$ were added to cast iron with a low carbon equivalent, and the nitrogen content and formation of defects then determined.[3] With a gas content of 140 ppm, fissure defects arose; with a gas content of over 300 ppm round gas blowholes formed. Technically, these high gas contents are meaningless.

In addition to the organic binders, bentonite-bonded sands can also have an influence on these defects. The proportion of inflowing nitrogen-bearing core sand can have an influence, as well as the nitrogen content of the carbon carrier. To avoid defects, it is recommendable to keep the bentonite and water content as low as possible.[1, 5] There is no standard reference available for the effectiveness of carbon carriers, but the use of highly active carbon carriers with a low nitrogen content appears practical where these defects are experienced.

The addition of barium sulphate, which is recommended in the literature,[5] is also effective. However, problems arise due to the reduction of the sulphate to sulphide and the subsequent formation of barium hydroxide and hydrogen sulphide, so limiting the extent to which this technique may be applied

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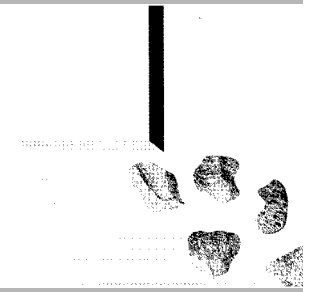   Lamellengraphit
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Fig. 18:   Micrograph of porosity in a grey iron casting. Distinctly rounded cavities strongly influenced by gas liberation.
Scale: 10 mm ≙ 0.06 mm

Micro-cavities

Assistance for decisions → P. 143
Sand control → P. 179

Characteristic features

Spongy, aerated or micro-porous structure at positions in the casting which are last to solidify.

Incidence of the defect

The defect occurs at those parts of the casting that are last to solidify, and particularly at points where material accumulation has occurred, points of transition between different wall thicknesses and also in the proximity of the gate.

This defect can occur especially when casting alloys with a wide solidification range.

Explanations

Micro-cavities occur as a result of the volumetric reduction of the metal with declining temperature and slurry-type solidification. It is difficult to differentiate these defects from those arising due to gas precipitation and inclusion. The defect is regarded as micro-cavitation where the influence of volumetric contraction predominates, and as micro-porosity when it has been primarily caused through shrinkage and gas precipitation.

Possible causes

Metallurgical
• Solidification interval too large
• Gas content in melt too high

Clay-bonded sand
• Gas formation too high
• Low heat removal rate

Resin-bonded sand
• Gas formation too high

Moulding plant
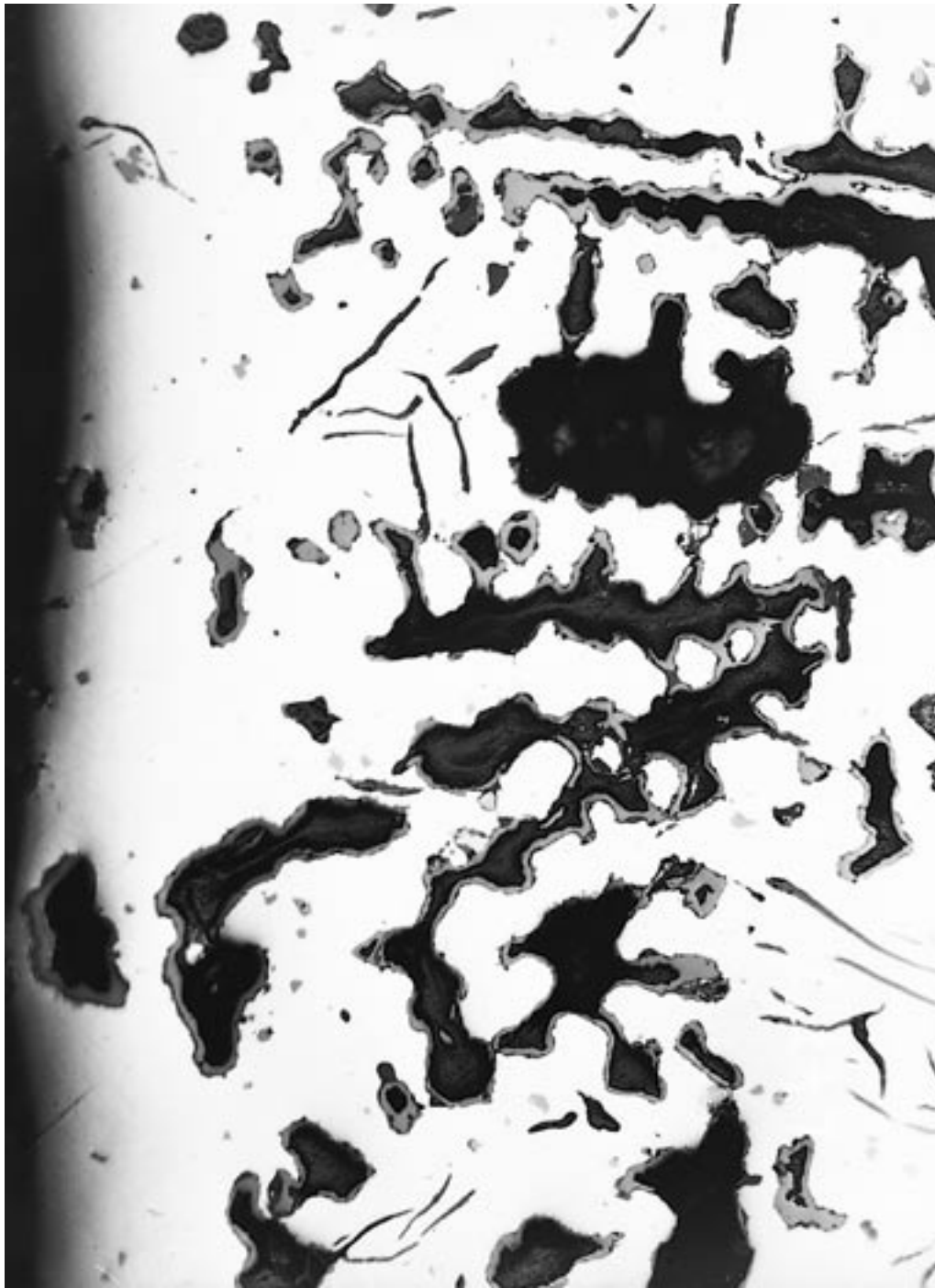• Mould stability too low
• Radii on patterns too small

Fig. 19:   Micrograph of a grey iron casting. Micro-cavities in the surface zone, partially oxidized surface.
           Scale: 10 mm ≙ 0.06 mm

Remedies

Metallurgy
- Reduce solidification interval; if necessary, grain refinement.
- Reduce gas content in the melt; if necessary, remove gases by nitrogen or argon flushing.

Clay-bonded sand
- Reduce release of gas from the moulding sand. Reduce contents of bentonite, carbon carrier and inert dust.
- Reduce water content in the moulding sand.
- Apply facing sand at critical points. Improve heat removal.

Resin-bonded sand
- Reduce release of gas from cores. Improve venting of gases.
- Add granular iron or facing sand with higher thermal conductivity at critical points.

Moulding plant
- Make moulds more stable by increasing compacting pressure. Compact mould more evenly.
- Round off the edges of patterns. Reduce "hot spots" by increasing the edge radii.

Background information

All alloys with a wide solidification range tend towards micro-shrinkage. Non-directional solidification takes place at over-heated points. The volumetric contraction at these points through cooling and solidification cannot be offset by feeding metal from other regions of the casting. Gases from the melt or over-heated parts of the mould diffuse into the micro-cavities and enlarge the micro-pores.

The formation of micro-porosity in copper alloys such as copper-tin and copper-zinc during casting in green-sand moulds can be avoided by directional solidification. This requires pouring at higher temperatures.

With iron-carbon alloys, investigations have been carried out regarding the influence of graphite expansion,[2−5] precipitation of gases out of the melt[6] and gas evolution from mould and coating materials.[7−9]

In order to avoid micro-porosity, it is recommended to work with carbon equivalents of around 0.95.[10] Solidification in critical regions should occur quickly,[11] for which purpose facing sand can be applied at these positions. Use of chromite or olivine sands has proved to be effective. Still better heat removal can be achieved by the application of chills in critical regions. Gas evolution from the mould and core regions must be minimized. With bentonite-bonded sands, the clay and water contents should be as low as possible. The same applies to the amount of binder in cores.

Because "hot spots" promote the occurrence of micro-porosity, it is necessary to avoid sharp edges on the patterns.

As indicated above, as a melt solidifies, small voids develop due to micro-shrinkage, creating defects known as micro-cavities or (micro-)porosity. The porous castings, known as "leakers" are either scrapped or require a costly sealing rework.[1]
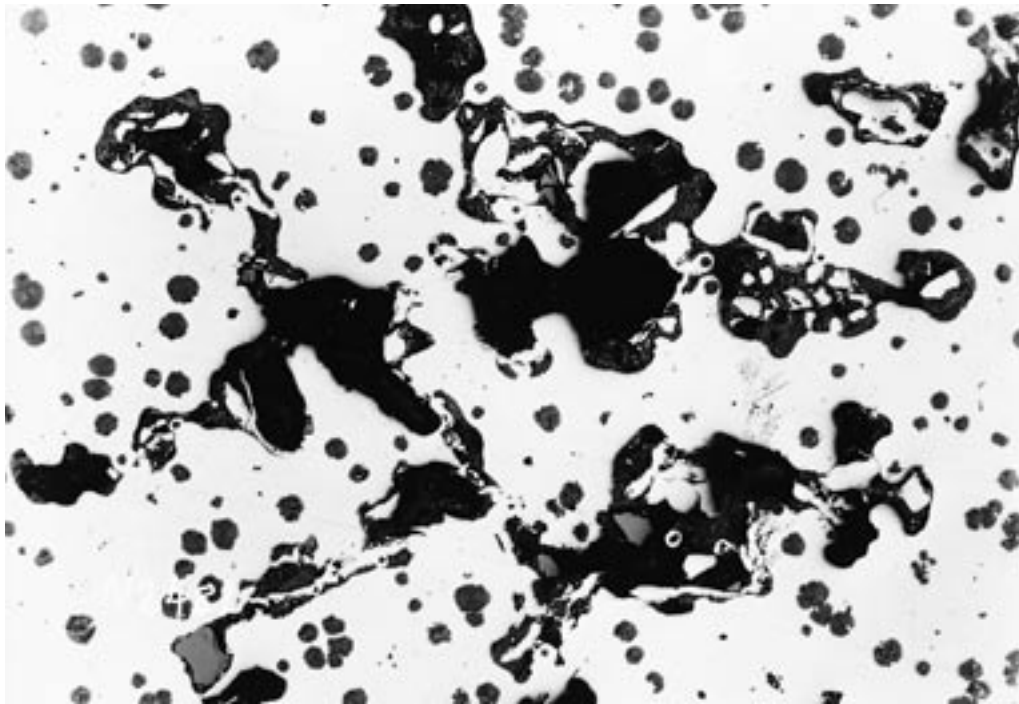
Fig. 20:   Micrograph of an SG iron casting. Micro-cavities in the surface zone, partially oxidized surface.
Scale: 10 mm $\hat{=}$ 0.08 mm

This process of volumetric contraction (volume deficit) causes micro-cavities to form at the points at which final solidification takes place. In terms of the casting technology applied, therefore, it should be ensured that such micro-pores are immediately resealed by positioning feeders at the appropriate locations, or by locating chills in the vicinity of the final solidification point in order to induce directional solidification. The point of final solidification is then transferred to the feeder.

In cases of solidification with dendritic growth at the solidification front (solid/liquid interface), intergranular (also known as intercrystalline) voids can occur which cannot be sealed by replenishment from the feeder. Gases precipitating from the metal melt may also collect in these micro-cavities. Consequently, it is difficult to distinguish between micro-porosity due to volume deficit and that resulting from gas precipitation.[2]

As this defect is primarily attributable to metallurgical causes, the first course of action should be to consult the prioritized list provided under the remedial flow chart in order to determine which of the causes indicated are the most likely culprits.

Hasse[3] recommends CE values < 0.95 as a means of preventing micro-porosity in cylinder blocks. The iron oxide content in the slag of the cupola should also be kept as low as possible.

In all cases, the solidification rate of the casting should be maximized. Nieswaag-Prabhakov-Zuithoff[4] investigated solidification rates ranging from 0.5 to $40 \cdot 10^{-4}$ cm/s, analysing the structure and also the casting properties produced by directional solidification. Their findings indicate that high speeds of solidification and low sulphur and phosphorus contents are beneficial.

Thury[5] reports on the growth and micro-cavitation of spheroidal graphite (SG) cast iron, highlighting the positive influence of a solid, inflexible mould. He too states that the casting should be made to solidify as quickly as possible. Lapin and co-workers[6] found that the tendency towards micro-cavitation decreases by approx. 50 % in solid moulds.

Venugopalan[7] identified an interrelationship between gas precipitation and the degree of porosity in non-ferrous metal castings, determining the degree of porosity both through density differential testing and ultrasonic damping measurement.

Smith[8] recommends the application of inert gas flushing with argon; and a further paper[9] reports on the benefits of continuous melt degassing.

In terms of mould structure, particular attention should be paid to the core binders and their gas evolution as a means of combating such defects. While Croning cores release up to 140 ml of gas per g of core sand, the figures for cold box cores and furan binders lie in the region of 80 – 90 ml/g core sand. Epoxy-SO$_2$ binders and the new furan hot-box binders offer particularly low values of around 60 ml/g core sand.[10]

Rapidly cooling moulding materials such as zircon, chromite and olivine sand are primarily used for steel casting, with their high refractory qualities also being utilized to good advantage. Significantly more effective is the careful placement of chills of appropriately varied shape and mass at the points of final solidification.

As also described in relation to angular blowholes, points and sharp edges in the mould or core that extend into areas very close to the thermal centre are dangerous as these can cause gas release from the moulding sand due to the suction effect arising from the evacuated condition of the thermal centre.

The defect does not always take the form of a neat pore or blowhole; this is particularly apparent in the case of non-ferrous metals. Consequently, the pattern should be constructed so that such points and sharp edges are extensively avoided.

An overview of relevant literature can be found in VDG-Fachbibliothek No. 288 "Porositäten von Gußeisen mit Lamellen- und Kugelgraphit"[11] (German Foundrymen's Association, Technical Library No. 288, "Porosity in flake and spheroidal graphite cast iron").
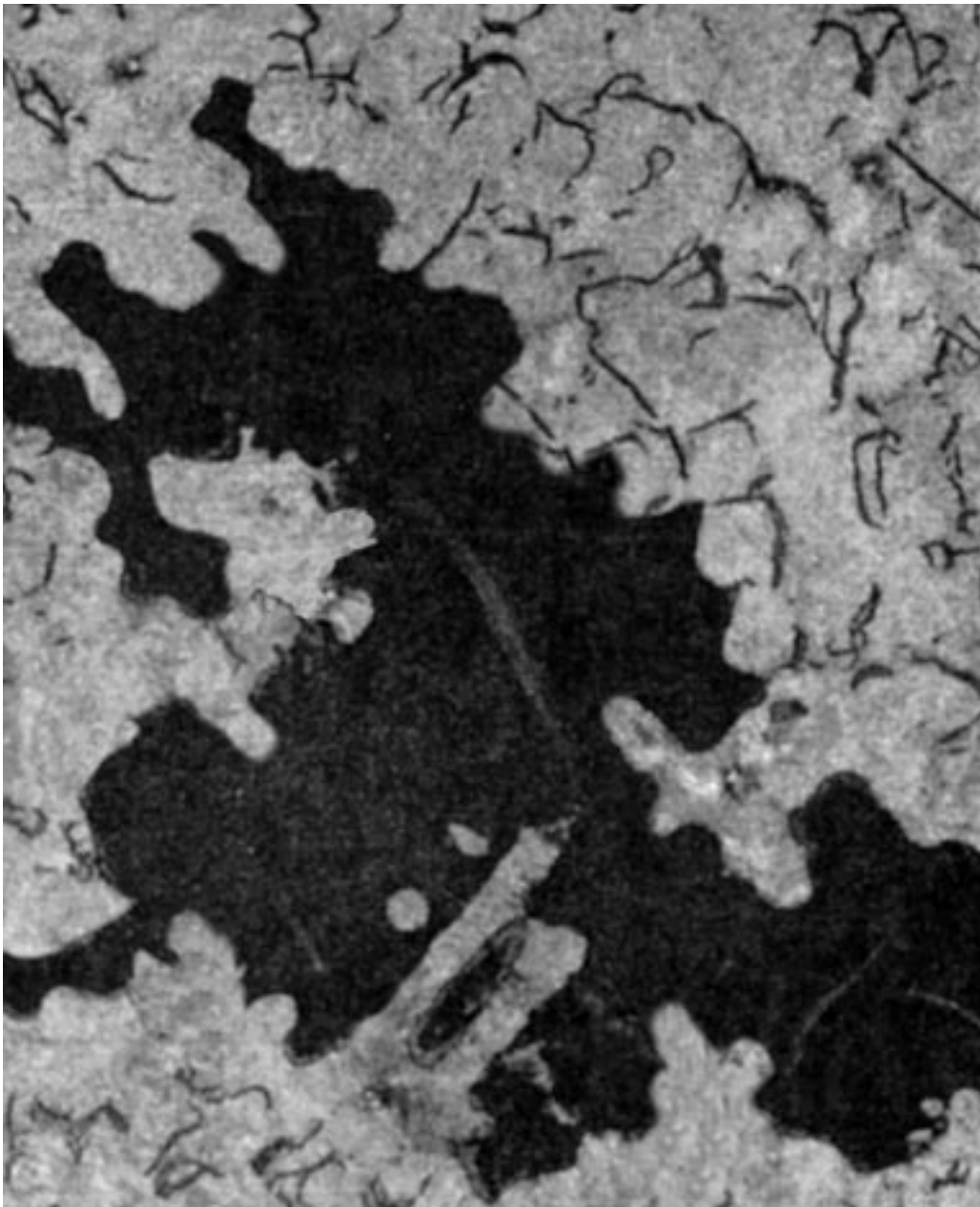
Fig. 21:   Micrograph of porosity in a grey iron casting. Interdendritic microstructure. Minor influence of liberated gases.
             Scale: 10 mm ≙ 0.06 mm

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11 Nieswaag, H.; Prabhakar, K. V.; Zuitholt, A. J.
    Eigenschaften und Gefüge von gerichtet erstarrendem eutek-
    tischem Gußeisen mit Lamellengraphit
    43rd International Casting Congress, 1976, Bucharest,
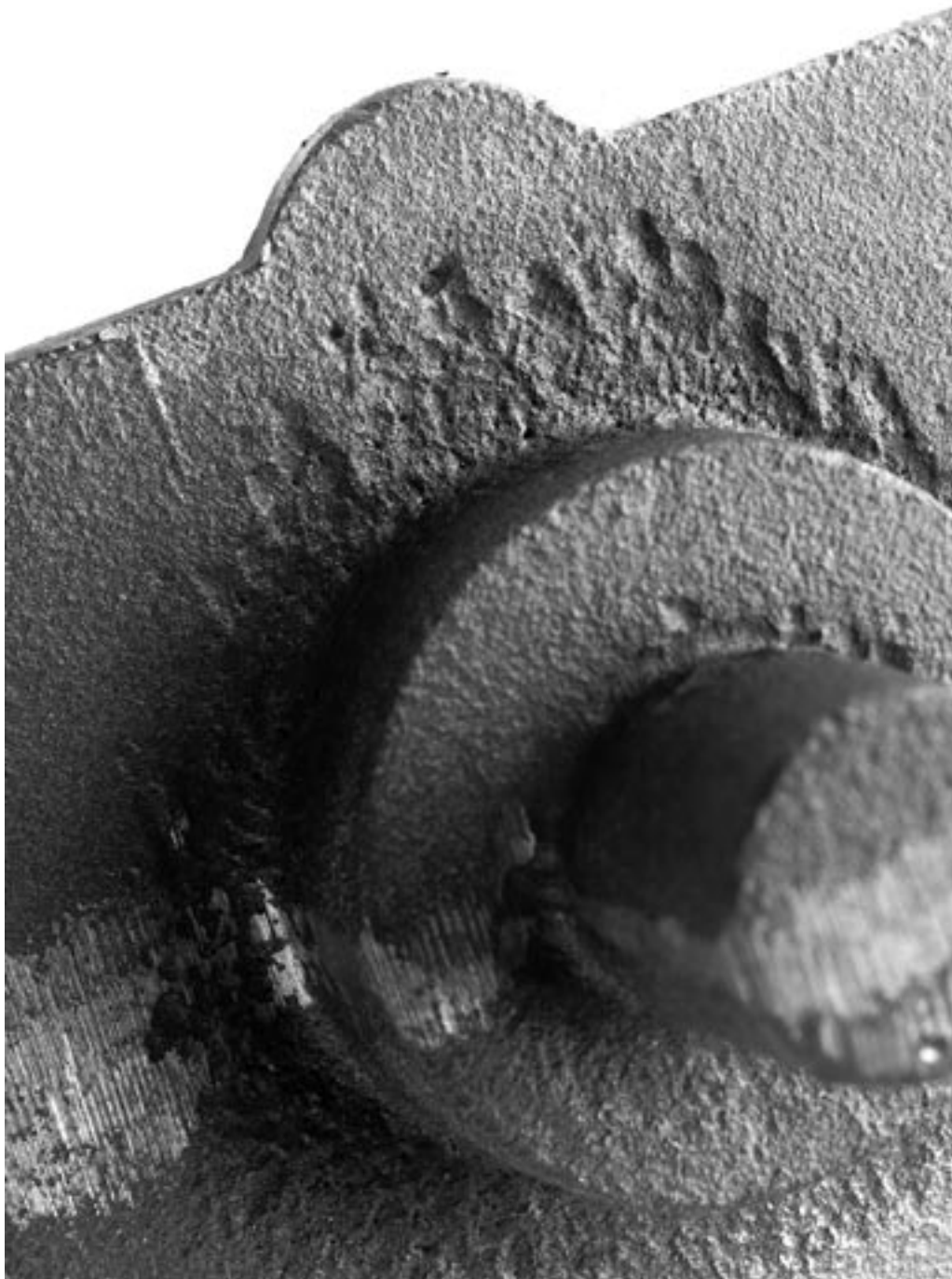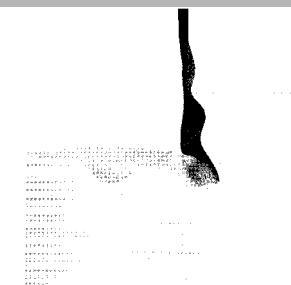   Paper No. 14, P. 14

Fig. 22:   Heavy SG iron casting. Pronounced surface pitting at so-called "hot spots".
Scale: 10 mm ≃ 6.5 mm

Pitted surfaces

Characteristic features

Formation of craters on castings of SG cast iron, particularly at very hot sections. Can occur in isolation or in wider-area clusters. Graphite degeneration occurs beneath the crater.

Incidence of the defect

The defect occurs exclusively in SG iron castings when poured into bentonite-bonded sand, predominantly at the positions in the sand which are subjected to high thermal loading.

Explanations

The defect occurs only in the presence of fluorides, which are either introduced into the sand through exothermic feeders or are used for the treatment of the melt. Since oxide formation and graphite degeneration are typical characteristics in the deeper parts of the pits and craters, an oxidizing influence can be assumed.

In our opinion, fluorides destroy the protective magnesium oxide layer on the surface of the molten iron. Water vapour from the green sand mould then reacts on the surface with the residual magnesium content of the melt.

Possible causes

Clay-bonded sand
- Proportion of exothermic feeder residues too high.
- Insufficient replenishment of moulding sand, consequently fluoride content too high.
- Moisture content too high.

Metallurgical
- Residual magnesium content of the melt too high

Remedies

Clay-bonded sand
- Reduce the fluoride content in the moulding sand by screening out the feed residues. Use feeders which adhere to the metal, replenish with new sand.
- Use insulating feeders or those with reduced fluoride content.
- Reduce water content through improved bentonite development, reduce bentonite content, use high-quality bentonite with a high montmorillonite content.
- Use highly active lustrous carbon producers with rapid release of gas.

Gating and pouring practice
- Reduce the number of exothermic sleeves, use insulating materials.

Fig. 23:   SG iron casting. Pronounced craters in the top part due to use of cryolite for slag liquefaction.
Scale: 10 mm ≙ 33 mm

Background information

The defect is barely mentioned in the literature, the mechanism is unknown outside our company. The single reference describes the increased susceptibility of SG cast iron with a high silicon content (3 %).[1]

Since the actual defect is caused by the reaction of water vapour with the residual magnesium content of the melt after the protective oxide layer has been destroyed by fluorides, any action which reduces the fluoride and water content in the moulding sand will be effective.

Feeder auxiliaries

In order to achieve the reaction

$$4\,Al + 3\,O_2 \rightarrow 2\,Al_2O_3$$
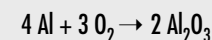
all exothermic feeders contain fluorides which destroy the aluminium oxide layer on the aluminium powder. Depending on the binder, the aluminium used and the oxidant, it is possible to work with different amounts of fluoride. The user should know the fluoride content of the feeder.

There is also the option of using sodium silicate-bonded feeder sleeves which adhere to the metal feeder and are removed with it. However, it should be noted that the fluoride content in sodium silicate-bonded feeder sleeves is normally higher. It is often possible to use insulating sleeves that are free of fluoride.

Moulding sand

The higher the water content in the moulding sand, the faster a reaction with the surface of an SG iron casting can occur when a critical fluoride content is exceeded. All measures for reducing the water content, and above all for reducing the bentonite content, are effective. Here, it is recommendable to use bentonite with a high montmorillonite content and a high cohesive capacity. In addition, improved bentonite development will result in a reduction in crater formation.

The use of carbon carriers with a high capacity for forming lustrous carbon also leads to a reduction of crater formation. Reduction of the water content in the moulding sand as well as suppression of water vapour from the mould cavity could also be beneficial.

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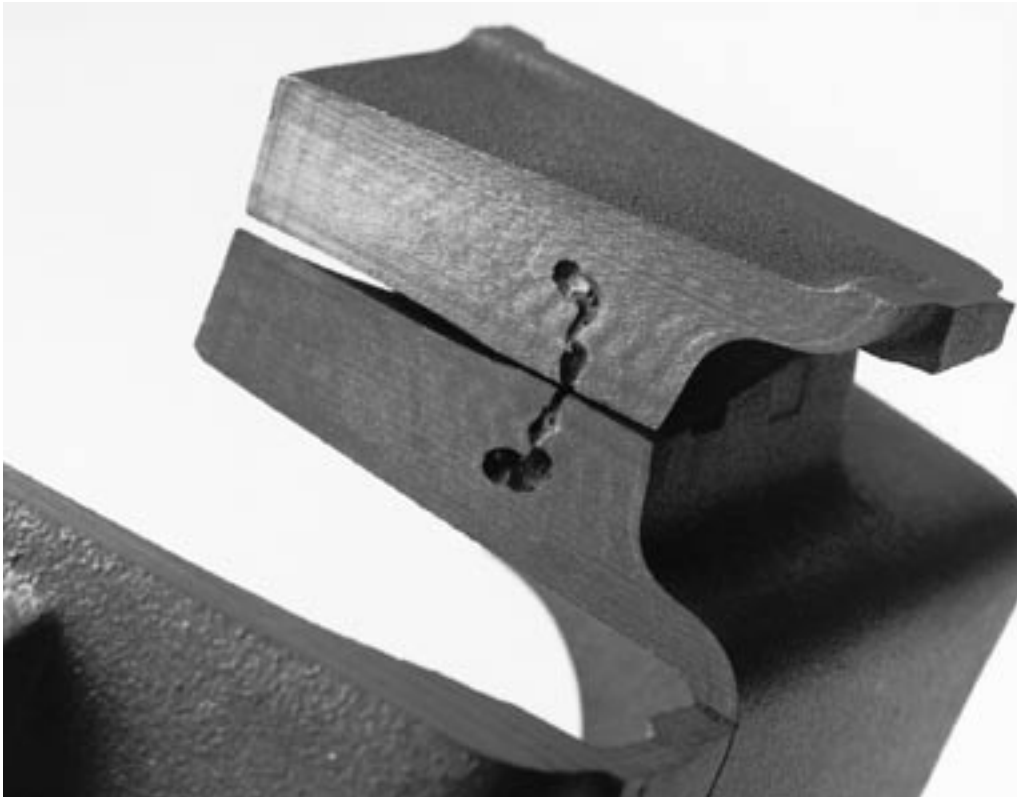
Fig. 24:   Grey iron casting. Section through a surface blowhole. The cut-out segment lies on top of the rest of the casting.
            The blowhole is almost invisible at the casting surface. Scale: 10 mm ≙ 8 mm

Surface blowholes

Characteristic features

Individual or groups of cavities. Mostly large with smooth walls.

Incidence of the defect

Gases entrapped by solidifying metal on the surface of the casting, which results in a rounded or oval blowhole as a cavity. Frequently associated with slags or oxides.

The defects are nearly always located in the cope part of the mould in poorly vented pockets and undercuts. The formation of blowholes is more predominant in grey iron castings than in SG iron.

Possible causes

Resin-bonded sand
- Inadequate core venting
- Excessive release of gas from core
- Excessive moisture absorption by the cores
- Low gas permeability of the core sand

Clay-bonded sand
- Moisture content of sand too high, or water released too quickly
- Gas permeability of the sand too low
- Sand temperature too high
- Bentonite content too high
- Too much gas released from lustrous carbon producer

Moulding plant
- Compaction of the mould too high

Gating and pouring practice
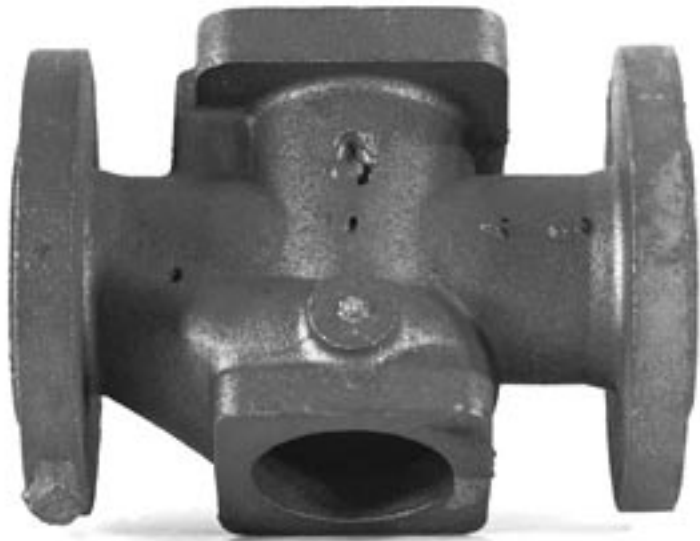- Casting temperature too low
- Metallostatic pressure too low when pouring

Fig. 25:   Low-alloy grey iron casting. Formation of surface blowholes in the top part.
            Scale: 10 mm ≙ 33 mm

Fig. 26:   Formation of a large blowhole in the top of a grey cast iron radiator.
            Scale: 10 mm ≙ 8 mm

Remedies

Resin-bonded sand
- Improve core venting, provide venting channels, ensure core prints are free of dressing
- Reduce amounts of gas. Use slow-reacting binder. Reduce quantity of binder. Use a coarser sand if necessary.
- Apply dressing to cores, thus slowing down the rate of heating and reducing gas pressure.
- Dry out cores and store dry, thus reducing absorption of water and reducing gas pressure.

Clay-bonded sand
- Reduce moisture content of sand. Improve conditioning of the sand. Reduce inert dust content.
- Improve gas permeability. Endeavour to use coarser sand. Reduce bentonite and carbon carrier content.
- Reduce sand temperature. Install a sand cooler if necessary. Increase sand quantity.
- Reduce bentonite content. Use bentonite with a high montmorillonite content, high specific binding capacity and good thermal stability.
- Use slow-reacting lustrous carbon producers or carbon carriers with higher capacity for producing lustrous carbon. In the last instance, the content of carbon carriers in the moulding sand can be reduced.

Moulding plant
- Reduce compaction of the moulds. Ensure more uniform mould compaction through better sand distribution.

Gating and pouring practice
- Increase pouring temperature. Reduce the pouring rate as appropriate.
- Increase metallostatic pressure by changing the gating system. If possible raise the cope flask.

Background information

The occurrence of gas cavities and blowholes is dependent on the gas volumes present and their pressure. If it is not possible to discharge the gases from the mould cavity, they will become trapped in the liquid metal.

There is a great danger of surface pitting on cores because they are surrounded by liquid metal and the gaseous reaction products are primarily removed through core prints. Blowholes are more frequently observed with smaller cores. It is recommended to use coarser sands and a corresponding application of mould dressings.[1] Cores with an unfavourable shape should contain waste gas channels. The necessary channel cross-sections for gas discharge from cores in relationship to core binders and geometry are thoroughly investigated in.[2] Obstruction of gas discharge results in bubbles being trapped in the metal. This problem also occurs with large gas discharge cross-sections when using phenolic resins. Hygroscopic binders such as sodium silicate require large cross-sections for gas discharge. Conversely, drying the cores can combat the occurrence of blowholes. Use of cold cores in hot moulds can lead to water adsorption with hygroscopic binders. This can result in explosive vaporization and the associated defects.

With bentonite sands, blowholes also primarily occur through the formation of water vapour.[3] This can be countered by reduction of the pouring rate and avoidance of impingement of the metal flow on the mould wall. When this defect occurs, the gas permeability of the sands should be as high and the water content as low as possible. Contents of all water-absorbing materials like inert dust, bentonite and carbon carriers should be minimized. Under certain circumstances, this necessitates the use of clays containing large percentages of montmorillonite as well as highly active carbon carriers. It is also recommended to develop the moulding sand as well as possible. Well-developed sands require less water and release this slower during heat-up. The occurrence of condensed water should be avoided. There should be no temperature differences between cores and moulds. Water can also precipitate on chaplets or chills and lead to gas defects on account of the absence of gas permeability. Frequently used chills can exhibit hairline cracks in which capillary condensation of water vapour can occur and lead to gas defects during pouring.

It is important to avoid excessive compaction in the moulding plant. In cases of high compaction, a check should be carried out to determine whether the compacting pressure needs to be reduced.

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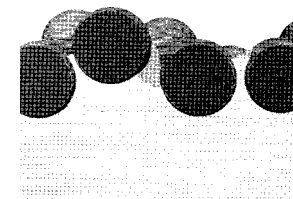 Gießerei 75, 1988, P. 238–245

Fig. 27:   Grey iron casting. Penetration at the hottest spot adjacent to the ingate.
                Scale: 10 mm ≙ 8 mm

Penetration

Assistance for decisions → P. 151
Sand control → P. 181

Characteristic features

Degree of roughness which is greater than the size of sand grains, at hot spots or under-compacted sections.

Incidence of the defect

Penetration particularly occurs at positions where parts of the mould have been heated to a greater degree (edges, thick-walled castings, near to the gate), and at sections where the sand has been poorly compacted.

Explanations

Physical penetration is said to occur where the depth of ingress is larger than the size of the sand grains and there is no chemical reaction between the moulding material and the infiltrating metal. However, if there is a reaction, this is said to be penetration due to chemical reaction (q.v.). In addition to penetration through exceeding the critical metallostatic pressure, this defect can arise through explosions (see Explosive penetration) and, with iron-carbon alloys, through graphite expansion (this latter is not dealt with here).

Possible causes

Clay-bonded sand
- Sand too coarse
- Insufficient carbon carriers
- Insufficient fines
- Excessive compactability

Resin-bonded sand
- Sand too coarse
- Insufficient compaction of cores

Moulding plant
- Insufficient and non-uniform mould compaction

Gating and pouring practice
- Mould and core sections overheated

Remedies

Clay-bonded sand
- Make the sand finer by using finer inflowing core sand, or by adding finer sand to the circulating sand.
- Increase quantity of carbon carrier. Increasing the lustrous carbon producing capacity reduces the wetting of the surface of the sand.
- Increase coke content; this helps to further reduce the pore size.
- Increase quantities of fines. The silica contents of the dust removed from the coke residues make suitable fines.
- Reduce the compactability of the sand. This increases its flowability. Better compaction is also possible.
- Flowability can be improved by using carbon carriers containing graphite, or combinations of bentonite/graphite.
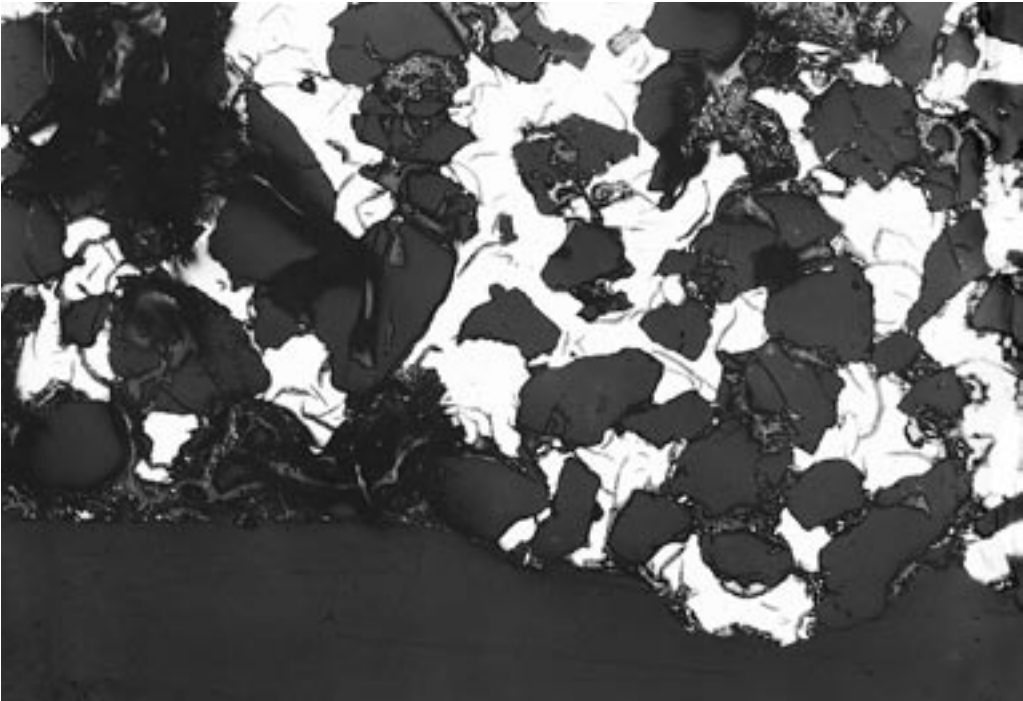
Fig. 28:   Micrograph of the metal / sand interface in a grey iron casting. Purely physical penetration of the liquid iron.
            Scale: 10 mm ≙ 0.08 mm

Resin-bonded sand
- Use finer core sands or add fines such as iron oxide.
- Compact cores more uniformly and effectively; if necessary use a less viscous binder.
- Dress cores at risk or, if necessary, increase the thickness of dressing.

Moulding plant
- Improve mould compaction. Increase the compacting pressure. Achieve more uniform mould compaction through better sand distribution.
- Products containing graphite improve compaction and increase packing density. At the same time, mould compaction becomes more uniform.

Gating and pouring practice
- Improve gating. Avoid excessive quantities of inflowing metal and thus local overheating.
- Increase spacing of patterns. Under certain circumstances this leads to reduction of overheated areas.
- Reduce casting temperature.

Background information

The critical pressure above which molten metal penetrates a porous sand surface depends on the surface tension, the pore diameter and the wetting angle of contact between the molten metal and the sand grains. If metallostatic pressure is greater than P_{crit}, penetration will take place.

$$P_{crit} = \frac{2\sigma}{r} \cos \Theta$$

P_{crit}	Pressure above which penetration occurs
σ	Surface tension, molten metal
r	Pore radius
Θ	Wetting angle of melt / sand contact

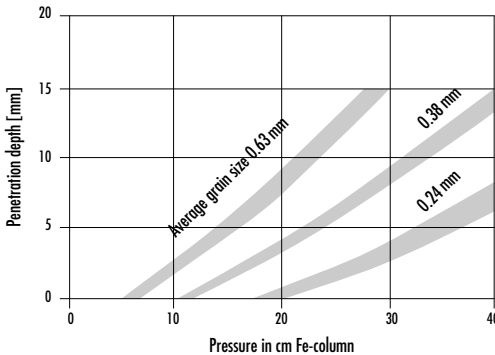Fig. 29 shows how the penetration depth of molten steel depends on metallostatic pressure:

Fig. 29
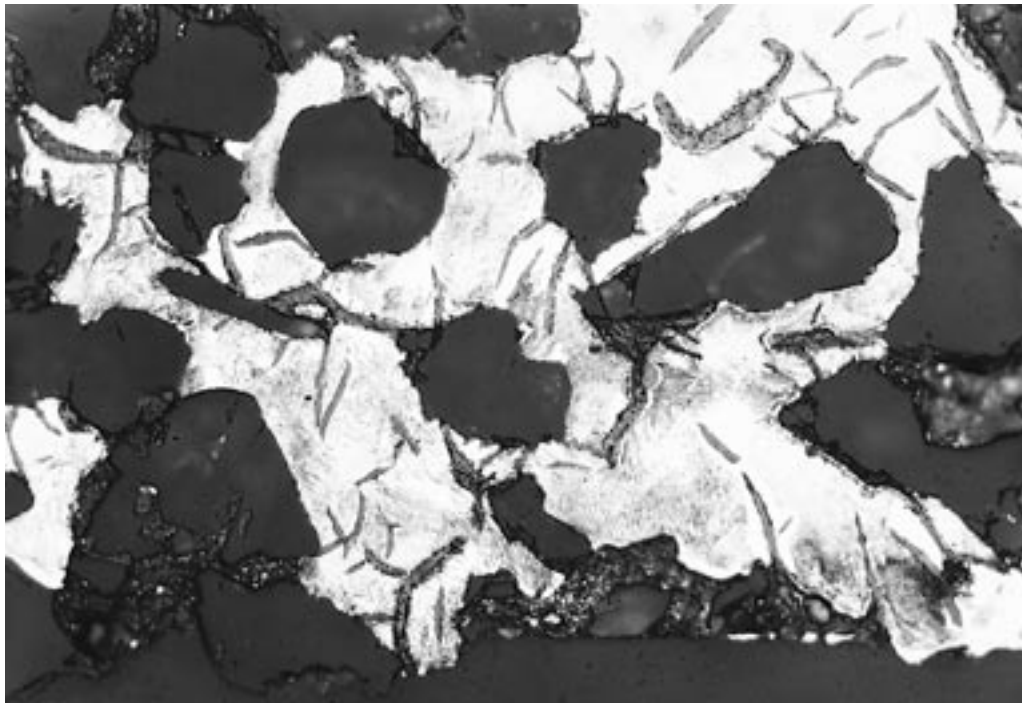
Fig. 30:   Micrograph through the metal / sand interface in a grey iron casting. No recognizable melt / sand reaction layers.
Scale: 10 mm ≙ 0.04 mm

Fig. 31 shows how the critical pressure for the onset of penetration of molten steel depends on the pore radius in the moulding sand.
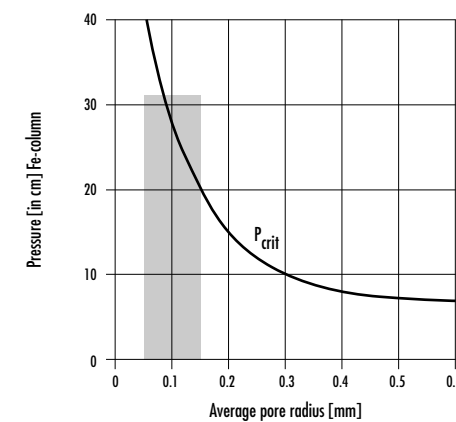

Fig. 31

Comparable results are also given for other molten metals and have been discussed in numerous papers.[1, 2, 3]

In the case of iron alloys, surface tension is increased by adding magnesium, aluminium and chromium. As a result, the tendency to penetration of SG cast iron is lower than that of grey cast iron.

In the case of resin-bonded mould parts, the likelihood of penetration depends heavily on the selected sand grain. Thus, Croning cores are prepared with fine sands, cold-box moulds with as coarse a sand as possible. Dressing, particularly of cold-box cores, is frequently necessary in order to avoid penetration. Penetration can occur if, during pouring, the dressing layer cracks because of expansion of the cores. Uniform compacting of the cores is necessary in order to keep the pore volume as low as possible.

If a high proportion of core sand flows into bentonite-bonded sands, the grain size of the core sand is crucially important to the grain size distribution in the green sand. Inflowing coarse cold-box sands increase the pore diameter. The critical pressure for the onset of penetration becomes lower. If penetration occurs, a finer sand may be necessary. An addition of extracted fines can help to avoid this defect. The lustrous carbon producing capacity has a lower influence on the pore diameter. It may be necessary to increase the amount or to use a lustrous carbon producer with higher coke formation. The mould surface should be uniformly and well compacted. Uniform compaction can be achieved by using products which contain graphite.

Penetration frequently occurs in the proximity of the gate. The inflowing quantities of metal are too great and cause too much heating of the moulding material in this area. The defect disappears when inflowing metal is better distributed.

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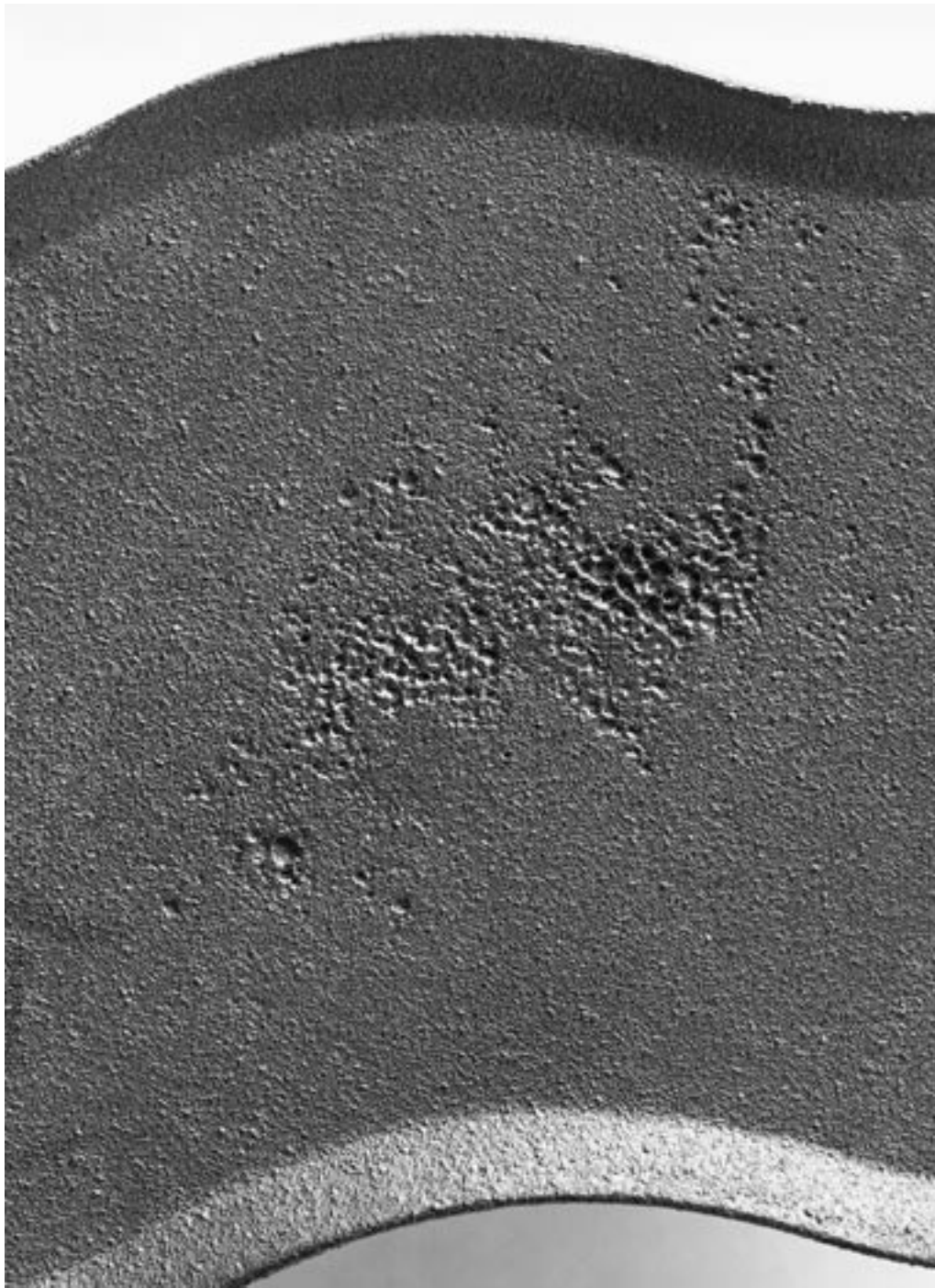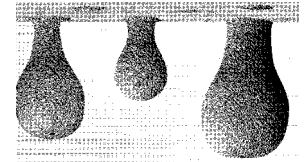Gießerei 60, 1973, P. 485–495

Fig. 32:   Large areas of surface blowholes/pinholes on a grey iron casting.
            Scale: 10 mm ≙ 4 mm

Pinholes

Assistance for decisions → P. 154
Sand control → P. 181

Pinhole porosity – surface blowholes

Differentiation is made between hydrogen pinholes, hydrogen-nitrogen pinholes and pinholes due to CO-slag reactions.

Characteristic features

Pores or small blowholes with a smooth surface. Sub-surface blowholes often contain a thin graphite film. There is no differentiation between hydrogen and hydrogen-nitrogen pinholes.

Pinholes due to CO-slag reaction also have smooth surfaces. The size of sub-surface blowholes can vary considerably. Blowholes occur in conjunction with oxygen-rich slag.

Incidence of the defect

Pinholes can appear individually or over an area. All areas of the casting can be affected. However, pinholes are more common in areas of the casting located away from the gate. Hydrogen and hydrogen-nitrogen pinholes occur in both grey and SG iron castings. Pinholes due to CO-slag reaction only occur in grey iron castings.

Explanations

Hydrogen and hydrogen-nitrogen pinholes
The formation of pinholes progresses in several stages:
1. The surface reaction of water vapour with other elements in the iron gives rise to metal oxides and atomic hydrogen which diffuses into the molten metal. Similarly, nitrogen-hydrogen compounds dissociate on the hot metal surface and diffuse into the molten metal. Dissociation of molecular nitrogen and hydrogen does not take place at the prevailing casting temperatures.
2. Due to enrichments in the slag, the metal oxides react with the carbon in the melt to form CO molecules which are precipitated from the melt and form micro-blowholes.
3. Hydrogen, and sometimes nitrogen, diffuse from the liquid metal into the CO micro-blowholes and increase their size.

Pinholes due to CO-slag reaction
These occur due to the reaction of heavily oxidizing, molten slags (mostly MnO / MnS-rich slags) with the carbon in the melt to form CO. Later in the process, hydrogen can also diffuse into these blowholes.
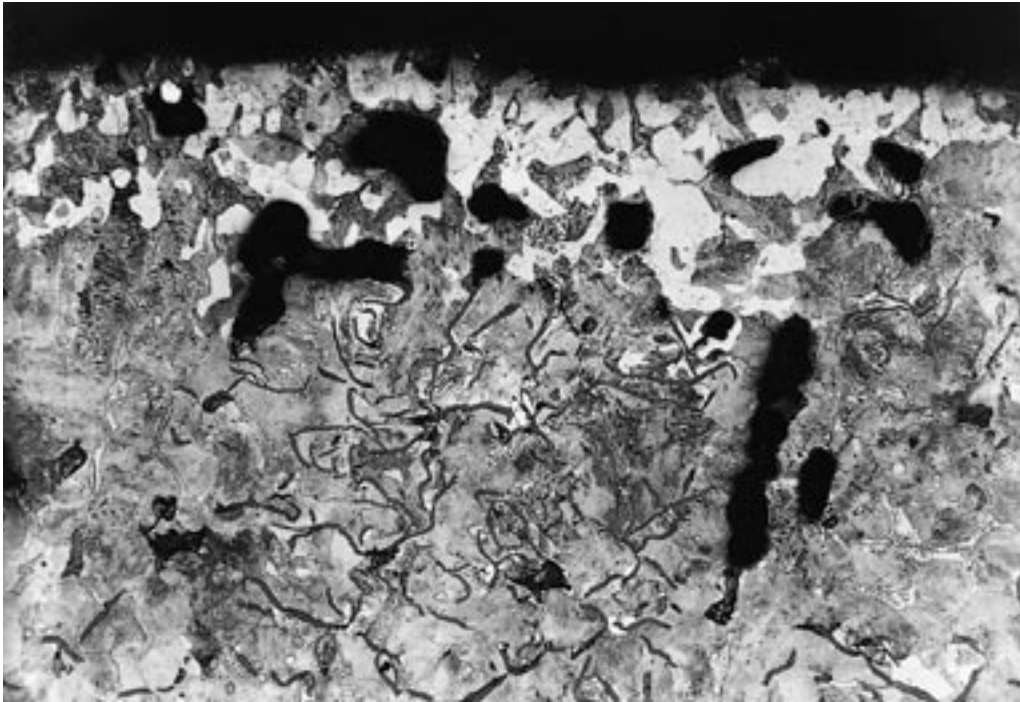
Fig. 33:   Section through the surface of a grey iron casting in the area of pinhole formation. Pinhole formation is promoted by surface oxidation, recognizable in the formation of ferrite. Scale: 10 mm ≙ 0.08 mm

Possible causes

Metallurgical
Ferrous metals
- Nitrogen content in the melt too high due to the charge composition.
- Proportion of oxides, hydroxides (rust) and other impurities in the charge materials too high
- Aluminium content in the melt too high
- Manganese and sulphur contents in the melt too high

Clay-bonded sand
- Nitrogen content in the sand too high
- Moisture content of the sand too high
- Lustrous carbon production in the moulding sand too low

Resin-bonded sand
- Nitrogen content in the core sand too high
- Proportion of nitrogen/hydrogen compounds in the core binder too high

Gating and pouring practice
- Pouring passages too long
- Too much turbulence and slag formation during pouring

Remedies

Metallurgical
- Use charge components with low nitrogen content, e.g. reduce the quantity of steel scrap.
- Use scrap and return material free of rust, water and oil impurities. Use circulating materials free of impurities adhering to sand and feeder auxiliaries.
- Use charge materials and especially inoculants and circulating materials with low aluminium and titanium contents.
- Deoxidize melts as well as possible. Avoid excessive supply of titanium or aluminium.
- Reduce the formation of slag, and particularly the formation of slags containing manganese sulphide, by adjusting the manganese and sulphur content.

Clay-bonded sand
- Reduce nitrogen content in the sand. Reduce the quantity of inflowing nitrogen-containing core sand. If necessary, add new sand to the circulating sand.
- Reduce the moisture content of the sand.
- Lower the bentonite content. Improve development of the moulding sand. If necessary, reduce inert dust content. Keep amount of lustrous carbon carrier at the minimum level.
- With an oxidizing atmosphere in the mould cavity, if necessary increase the quantity of lustrous carbon producer in the moulding sand. Avoid adding too much.

Resin-bonded sand
- Reduce the amount of binder. Use binder with lower nitrogen content.
- Improve core venting, dress core if necessary.
- Add iron oxides to the core sand mixture.

Gating and pouring practice
- Increase pouring temperature
- Reduce flow rate into the mould
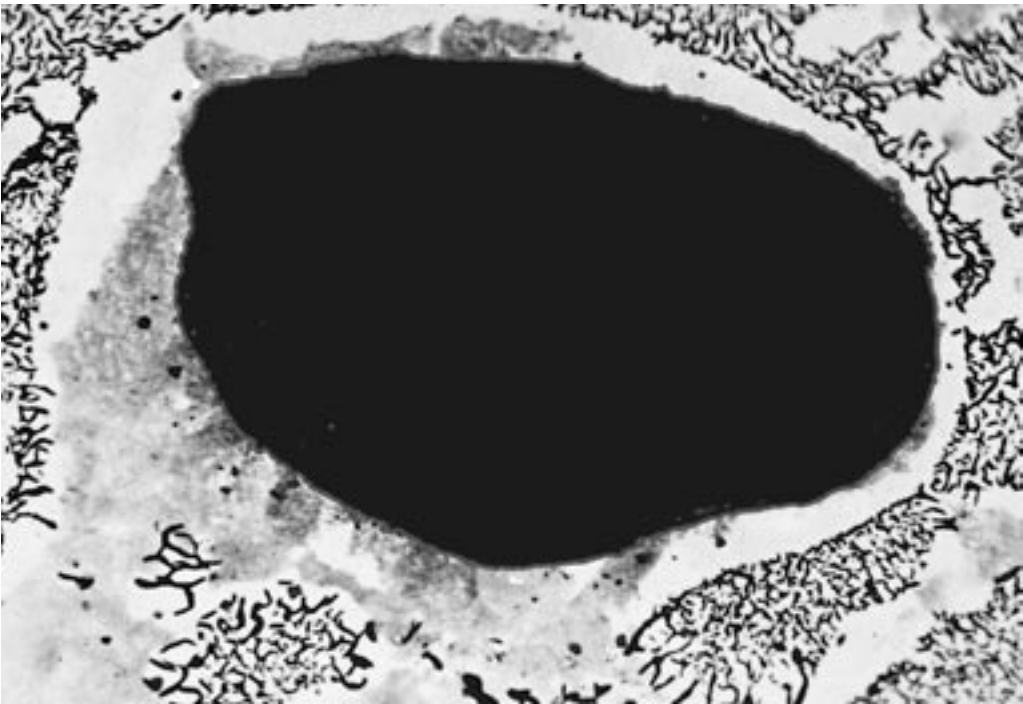- Avoid turbulence when pouring.

Fig. 34:   Section through a surface pinhole in a grey iron casting, hydrogen-nitrogen defect recognizable by the graphite film and the partial decarburization of the surface zones. Scale: 10 mm ≙ 0.05 mm

Background information

A distinction is made between pinholes caused by hydrogen, nitrogen-hydrogen and sub-surface blowholes due to slag / CO reactions.

Mechanism of pinhole formation

Blowholes/pinholes arise in a melt under the following conditions:

$$P = P_0 + \frac{2\sigma}{r}$$

P	Necessary gas pressure to form a blowhole
P_0	Atmospheric + metallostatic pressure
s	Surface tension of the melt
r	Radius of the blowhole

Calculations of the gas pressure at which blowholes/pinholes can occur shows that the melt must be considerably over-saturated with gases such as nitrogen and / or hydrogen.

Sub-surface blowholes can form on solid reaction products in the melt at considerably lower gas pressures (phase boundaries). Similarly, where CO bubbles are formed through the reaction of oxides with the carbon in the melt, the dissolved gases (nitrogen, hydrogen) diffuse into the molecular gas pockets and form pinholes.

Sufficient oxygen enrichment near the surface of the melt is necessary for the formation of CO bubbles. According to Gibbs, the formation of molecular CO blowholes is determined through the work to be expended:

$$A_k = \frac{4}{3}\sigma r^2$$

In the formation of CO bubbles, the surface tension of the melt is proportional to the work to be expended. According to Frenkel and Thompson, the intensity I of pinhole formation is described by the following equation:

$$I = A \cdot e^{\left(\frac{A_k}{kT}\right)}$$

The influence of surface tension on the formation of pinholes has been investigated. Higher surface tension suppresses pinhole formation.[1]

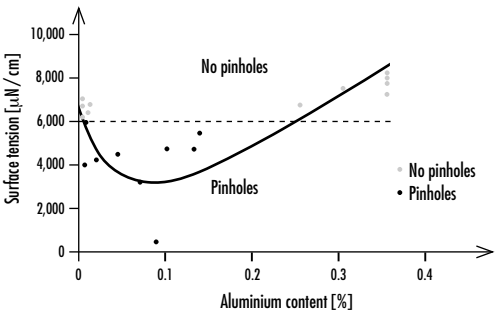*Surface tension at 1400°C*

Fig. 35:   Influence of aluminium content on surface tension and pinhole occurence in grey cast iron.
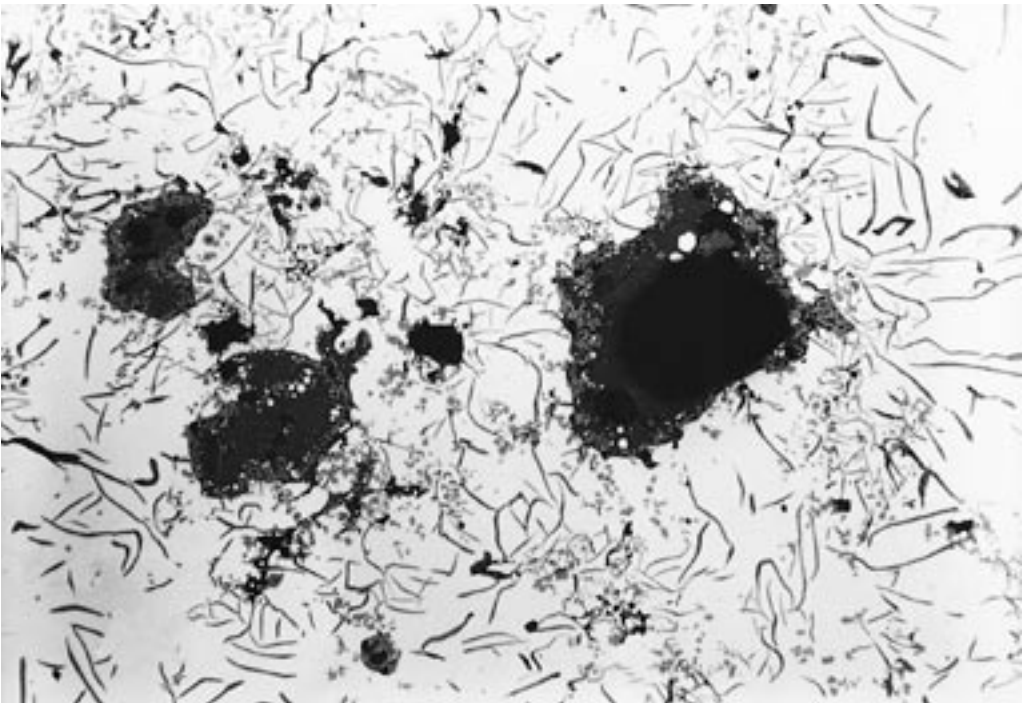
Fig. 36:   Micrograph of a slag / gas defect in a grey iron casting.
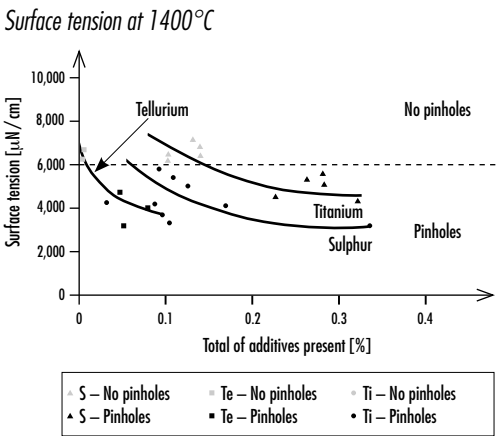Scale: 10 mm ≙ 0.1 mm

Surface tension at 1400°C

Fig. 37:   Influence of sulphur, titanium and tellurium content on surface tension and pinhole formation in grey cast iron.

Pinholes due to CO-slag reactions

In the formation of this defect, low-viscosity silicate slags rich in manganese oxide and enriched with manganese sulphide react with the carbon in the melt and form CO. With high manganese and low silicon contents, the manganese reduces silica from slags and the refractory lining, forming highly liquid manganese oxide slags. High sulphur contents enable the formation of MnS, which is enriched in the slag and makes the slags even more reactive.[2]
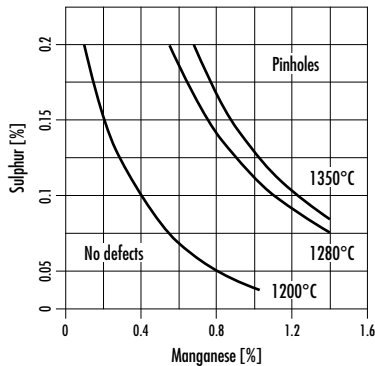

Fig. 38:   Influence of manganese and sulphur content and pouring temperature on the formation of pinholes.

In addition to pure CO pinholes, molecular CO bubbles can be regarded as the nucleus for hydrogen and hydrogen-nitrogen pinholes.

Hydrogen pinholes

Hydrogen is primarily introduced into a melt through the reaction of strong oxygen binding agents in the melt, e.g. aluminium, magnesium and titanium, with water vapour.

$$Me + H_2O \rightarrow MeO + 2H$$

The atomic hydrogen is immediately absorbed by the melt.

Water vapour is produced by moist refractories, rust-containing input materials and the binding clays used in the moulds, and is also present in the mould cavity air during pouring.

Table 1 shows how long a melt absorbs hydrogen from the lining of a cupola.

Tapping time	Hydrogen content [ppm]
7.00	5.6
7.20	4.2
7.40	3.0
9.00	2.2
11.00	1.8
12.00	1.4
14.15	1.6

Cold blast test cupola, tap weight in each case 400 kg.
Cupola diameter 140 cm
Acid furnace lining
The furnace was lined 24 hrs. previously.

Fig. 39:   Blowholes/pinholes over the complete surface of a grey iron casting.
Scale: 10 mm ≙ 8 mm

The precipitation of hydrogen is unlikely in a homogeneous melt. Where oxide nuclei or CO bubbles form, precipitation is more likely, due to the low pressure required. At high temperatures and pressures, the molecular hydrogen formed reacts with the carbon in the melt and forms methane, which breaks down to form graphite and hydrogen:

$$C_{dissolved} + 2H_2 \rightarrow CH_4$$
$$CH_4 \rightarrow C_{graphite} + 2H_2$$
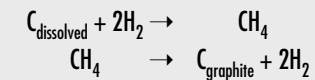
Whilst the dissolved carbon reacts with hydrogen, the precipitated graphite is not dissolved by the superheated hydrogen in the formation of methane.

As a result of these processes, hydrogen pinholes nearly always contain a thin graphite film. The bubbles are surrounded by a pearlite-free ferrite layer.

Hydrogen pinholes are normally round. Contrary to this, nitrogen pinholes have a dendritic shape. The explanation lies in the different rates of diffusion of the gases. Pure nitrogen blowholes/pinholes contain no graphite film.

Avoidance of hydrogen pinholes

Hydrogen is absorbed by an iron melt where the amounts of reactive elements are too high. Cast iron melts should be free of magnesium and, above all, aluminium. Aluminium contents as low as 0.01 – 0.1 % can lead to dangerous hydrogen absorption.

Excessive titanium contents, as particularly found in circulating materials, promote the formation of pinholes.

Since absorption of hydrogen usually occurs through the formation of water vapour, the content in the molten metal of hydroxides, rust, mould moisture, water combined in the clay etc. should be kept as low as possible.

The formation of pinholes can also be avoided if there is sufficient lustrous carbon producer in the mould. The reducing atmosphere prevents the formation of CO bubbles. Various authors have highlighted that admixtures of pit coal dust and other lustrous carbon producers can help to prevent pinholes.[3–5]

Nitrogen-hydrogen pinholes

In addition to hydrogen pinholes, nitrogen-hydrogen pinholes occur where nitrogen-containing binding agents are used. Such defects are primarily generated through the use of binders containing urea.

The nitrogen-hydrogen radicals are broken down near the surface of the melt, which immediately absorbs them in the atomic state.

These surface blowholes often have a graphite film and a ferrite seam like the hydrogen pinholes. They form in a similar way to that described under hydrogen pinholes. Many reports have been published on these pinhole phenomena.

Avoidance of nitrogen-hydrogen pinholes

These pinholes can occur where there is a high nitrogen content in the melt resulting from the use of charge materials such as steel scrap or nitrogen-containing carburizing compounds. Here, too, a crucial contribution is made by the combined action of gases from the mould cavity and the mould. High nitrogen contents in the melt (over 100 ppm), in the carburizing agent, in the core binder and in the bentonite-bonded sands should be avoided.

The use of increased proportions of lustrous carbon producers in the moulding sand to achieve a reducing atmosphere has also proved to be effective.

In the case of cores, the addition of iron oxides and barium sulphate will help to prevent this defect.

Pinholes due to CO-slag reactions

Under certain conditions, oxygen-rich slags can react with the carbon in the melt to form CO. Liquid iron oxide-rich slags also react this way:

$$FeO + C \rightarrow Fe + CO$$
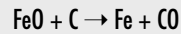
The pinholes may be observed on the surface of the casting but are sometimes not visible until it is machined. All slags formed during melting and pouring can become highly fluid through enrichment with FeO or MnO, and then react with carbon to form blowholes/pinholes.

Pinholes of this type mostly have slag inclusions in the pockets, such inclusions often containing MnS precipitations. The large influence of MnS on the formation of the pinhole can be traced back to the liquefaction of the slag and thus its increased reactivity.

Hydrogen also negatively influences this defect.

Avoidance of slag-CO surface pinholes

In order to avoid this surface defect, it is necessary to increase the pouring temperature, reduce the sulphur content and restrict the manganese content.

BCIRA recommends foundries to keep to a 0.7 % manganese content.

Other authors recommend that the manganese content be kept no higher than 0.4 % of the Si content.

It is also recommended that the melt be given little opportunity to oxidize. Turbulence during filling should be avoided and liquid-metal flow paths kept short. As water vapour has a strongly negative effect, the bentonite content in the moulding sand should be as low as possible.

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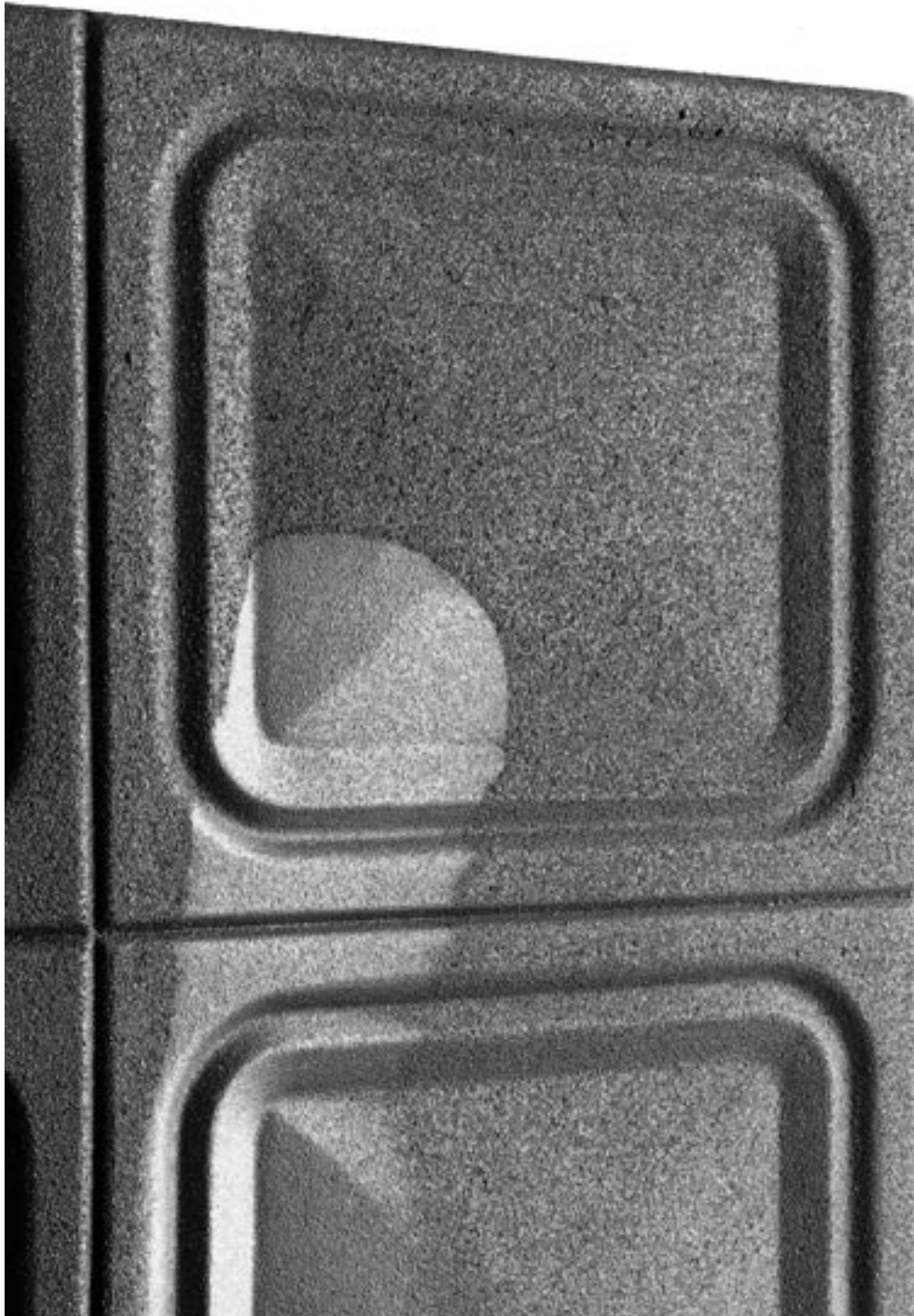AFS Research Reports 1979, P. 37

Fig. 40:　Grey iron casting. Surface roughness primarily equivalent to the sand grain size. Coarser roughness is caused by the breaking loose of sand and its adhesion to the pattern plate. Scale: 10 mm ≙ 13 mm

Surface roughness

Assistance for decisions → P. 157
Sand control → P. 182

Characteristic features

The casting surface exhibits a level of roughness corresponding to the size of the sand grains.

Incidence of the defect

The defect primarily occurs near the gate and in very hot areas, and is frequently to be regarded as an early stage of penetration. The defect is also found at positions where mould compaction is poor.

Possible causes

Clay-bonded sand
- Sand grains too coarse
- Too little lustrous carbon producer in the moulding sand
- Too few fines in the sand.

Moulding plant
- Too little compaction
- Too much adhesion of sand grains to the pattern
- Too little bonding of the sand grains in the mould surface

Gating and pouring practice
- Pouring temperature too high
- Metallostatic pressure too high

Remedies

Clay-bonded sand
- Use fine-grain sand. If necessary, refine core sand so as to adjust the fineness of the recirculating sand
- Increase production of lustrous carbon in the moulding sand. Adjust "active carbon content" to 0.35 % – 0.45 %
- Use carbon carrier that produces more lustrous carbon.
- Increase fines content. Increase coke formation in moulding sand if necessary increase return of dust in order to increase fines content.

Moulding plant
- Improve mould compaction. Increase compacting pressure. Improve sand distribution to achieve more uniform mould compaction.
- Reduce adhesion of sand grains to the pattern. Use a release agent or use it more frequently. Sufficiently heat pattern.
- Improve bonding of sand grains at the mould surface. Avoid rapid drying-out of the surface by means of better development.

Gating and pouring practice
- Reduce pouring temperature
- Improve gates. Avoid local overheating

Fig. 41: Very rough surface of a grey iron casting caused by adherence of sand grains to the pattern during moulding.
Scale: 10 mm ≙ 8 mm

Background information

With bentonite sands, the surface roughness of a casting is decisively influenced by the size of the sand grains.[1, 2]

Production of lustrous carbon also has a smoothing effect on the casting surface, but this is not as strong as that referred to above. Measurements of the depths of roughness were made in the research work referred to below.[1] In our judgement, lustrous carbon producers firstly have a smoothing effect through the formation of the pyrographite film and, secondly, through the reduction of wetting of the sand grains. Water vapour is generally regarded as having a negative influence.[3, 4] The yield of lustrous carbon decreases; at the same time, the reactivity of the melt increases through oxidation. The binding of water in the bentonite slows down the release of water vapour. Better development of the moulding sand results in smoother casting surfaces.[4] The proportion of fines also has an effect on the smoothness of casting surfaces,[1, 2] whereby it is essential that the fines present do not have a low melting point.

The degree of chamottization of a sand also influences the roughness of the casting.[5, 6] This is because of the increasing grain diameter and increased water requirement, which result in the reactions previously described.

A rough mould surface can also lead to a rough casting. This is caused by sand grains being detached from the mould surface and can be attributed to a loss in binding power of the bentonite through drying or poor bentonite development. The sand grains fall into the mould cavity and lead to sand inclusions (see casting defect "Sand inclusions"). In addition, where sand grains adhere to the pattern, it is necessary to examine the sand / pattern temperature, bentonite development, the release agent and its application.

The comments on sand grain size made at the beginning also apply to resin-bonded sands.

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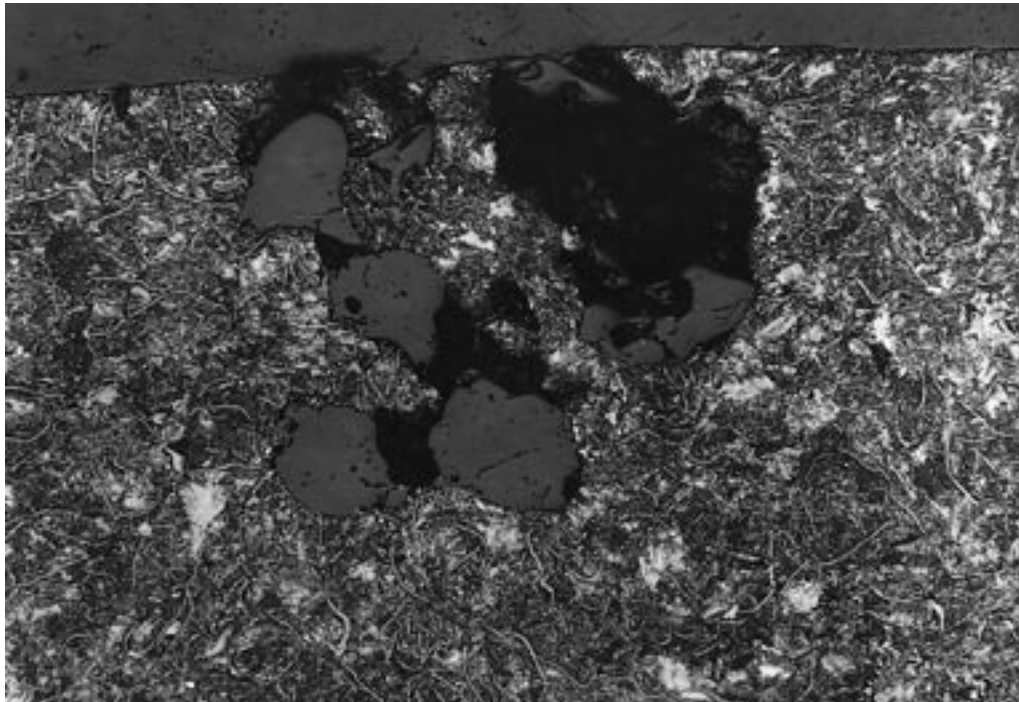Indian Foundry J. 31, 1985, P. 21−25 (English)

Fig. 42:   Inclusions of large areas of sand and individual sand grains in a grey iron casting.
            Scale: 10 mm ≙ 8 mm

Fig. 43:   Micrograph of an inclusion defect in a grey iron casting. The embedded sand grains are clearly recognizable.
            Scale: 10 mm ≙ 0.08 mm

Sand inclusions

Characteristic features

Irregularly formed sand inclusions, close to the casting surface, combined with metallic protuberances at other points.

Incidence of the defect

Sand inclusion is one of the most frequent causes of casting rejection. It is often difficult to diagnose, as these defects generally occur at widely varying positions and are therefore very difficult to attribute to a local cause. Areas of sand are often torn away by the metal stream and then float to the surface of the casting because they cannot be wetted by the molten metal. Sand inclusions frequently appear in association with CO blowholes and slag particles. Sand inclusions can also be trapped under the casting surface in combination with metal oxides and slags, and only become visible during machining. If a loose section of sand is washed away from one part of the mould, metallic protuberances will occur here and have to be removed.

Explanations

With bentonite-bonded moulds, sand inclusions can be caused by cod and edge disintegration, sand crust formation or erosion.

The latter results in the inclusion of individual sand grains. Sand crust inclusions and individual sand grains can also be detached from resin-bonded moulds, and are then included in the casting.

Possible causes

Moulding plant
- Break-up of mould sections during stripping of patterns, core setting or assembling of moulding flasks
- Uneven compaction of moulds, compaction too high in places.

Clay-bonded sand
- Low compactability
- Bentonite content too low, or poorly developed bentonite
- Inert material content too high
- Lump content too high
- High content of lustrous carbon producer

Resin-bonded sand
- Low core strength
- Excessive core mismatching

Gating and pouring practice
- Pouring rate too high, with heavy impact against mould wall surface resulting in erosion
- Ladle too far above pouring basin
- Pouring time too long

Remedies

Moulding plant

- Check moulds for pressure marks and, if necessary, insert pressure pads
- Carefully blow out mould cavities
- Improve pattern plates, increase pattern tapers and radii. Heat pattern plates and, if necessary, use release agent.
- Check the moulding plant for uniform flask stripping and overhaul moulding plant as necessary
- Automate core-setting. Check and, if necessary, modify core prints before start of production
- Ensure uniform mould compaction, avoid over-compacted sections

Clay-bonded sand

- Raise compactability and thus plasticity of the sand
- Increase bentonite content. Use bentonite with high specific binding capacity. Improve bentonite development by extending mixing time or by pre-wetting used sand
- Reduce inert dust content. Decreasing the dust content reduces lumps in the sand.
- Reduce content of lustrous carbon producer

Resin-bonded sand

- Increase the strength of the cores. Use greater proportion of binder.
- Compact cores more evenly and effectively and, if necessary, inject gas more evenly
- Avoid core mismatching.

Gating and pouring practice

- Avoid high pouring rates and impact of metal stream against mould walls
- Shorten pouring times, improve distribution of gates.

Background information

Metal flowing into the mould cavity can detach sections or individual sand grains from the mould during pouring, and transport them to remote parts of the casting. Portions of the gate are often carried away through erosion (see also casting defect "Erosion"). This leads to sand inclusions in the proximity of the gate of the casting. Measures required to counteract this are any of those which increase the resistance of the mould to erosion.

Edge disintegration results in whole sections of the mould being carried into the casting during pouring (see casting defect "Cods and edge disintegration"). Edge disintegration arises during moulding, during assembly of the moulds, during core-setting and, above all, when the sand has insufficient plasticity. Torn out areas of the mould cannot be visually detected and, during pouring, frequently cause disintegration of whole sections. All measures which increase the plasticity of the sand reduce susceptibility to this defect.

Scabbing (see casting defect "Scabbing") can also lead to sand inclusions in the casting. All measures to reduce compressive stress and increase green tensile strength reduce the risk of sand inclusions through scabbing. To determine the causes of sand inclusions, it is recommended to shot-blast castings together with gates and feeders. By this means, it is often possible to attribute sand inclusions to defects in the mould. By opening a mould which has been closed, it is frequently possible to ascertain pressure marks which could lead to sand defects.

In the case of resin-bonded moulds, sections can disintegrate as a result of excessively low strengths, thus leading to inclusions. When such defects occur, core compaction, strength and storage stability under elevated humidity must be examined.

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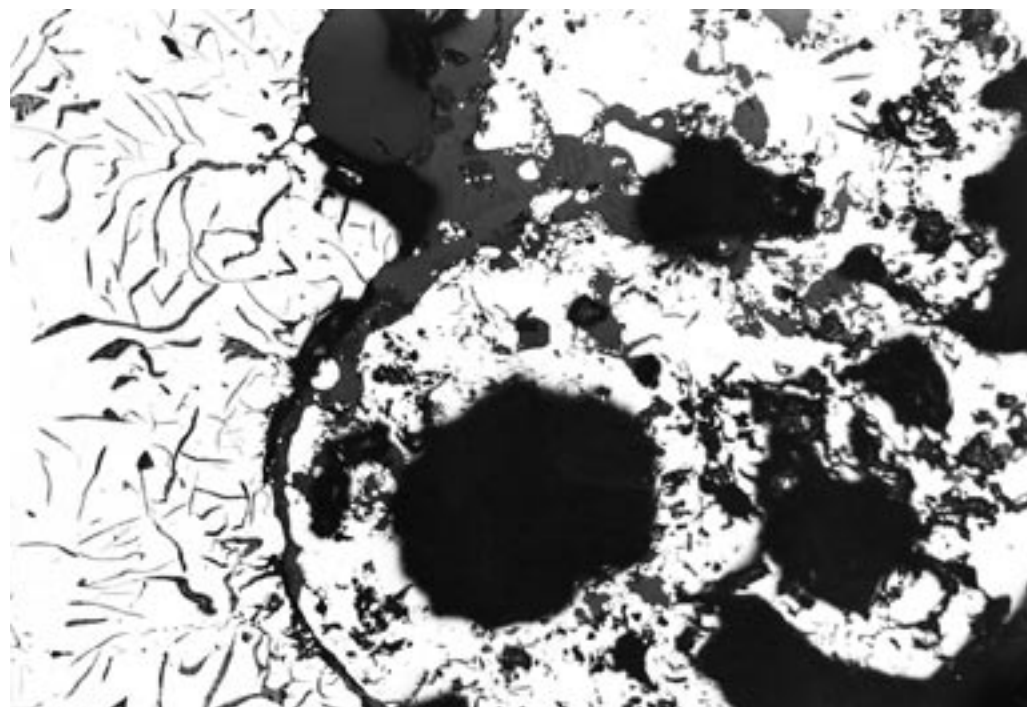Fondeur aujourd'hui, 259, 1974, P. 13 ,15, 17 (French)

Fig. 44:   Slag inclusions in the top part of a grey iron casting, in some cases still there, in others already removed by shot blasting.
Scale: 10 mm ≙ 8 mm

Fig. 45:   Slag inclusions and gas defects under the surface of a grey iron casting. Inclusions caused by turbulence.
Scale: 10 mm ≙ 0.08 mm

Slag inclusions

Characteristic features

Irregular-shape, non-metallic inclusions, frequently on upper casting surfaces, which may occur in association with gas blowholes.

Incidence of the defect

Slag is not only found at the microstructure grain boundaries but also on the surface of the casting. Slag may often appear in association with gas cavities.

Highly viscous slags more frequently appear in the microstructure of the casting. Low-viscosity slags rise more quickly to the surface of the casting. However, in the event of severe turbulence and a short solidification time, low-viscosity slag may also be included in the casting. During the casting of iron-carbon alloys, oxide inclusions and slag with a high oxidation potential (e.g. high manganese and ferrous oxide contents) react with the graphite, resulting in the formation of CO blowholes.

Other gases from the melt may migrate into the CO cavities.

Explanations

Slag and oxides occur when melting metals in the presence of oxygen. These frequently react with the furnace or ladle lining. When melting grey cast iron in a cupola, the oxides generated also react with the ash residues from the pit coal coke. In most cases this results in silicate slag. The metal flowing into the mould also forms oxides, which may react with the moulding sand and its components. Likewise, highly oxidizing additions (alloy components, inoculants) may be responsible for the formation of oxides and slag.

Possible causes

Metallurgical
- Oxide content of the charge too high
- High impurity levels of oxides and hydroxides in charge materials
- Poor or slow dissolution of inoculants
- Ladle lining too highly reactive
- Poor deslagging of the molten metal

Gating and pouring practice
- Casting temperature too low and pouring rate too slow
- Too much turbulence when pouring, and poor slag precipitation

Clay-bonded sand
- Proportion of inert dust too high
- Proportion of bentonite too low, bentonite poorly developed or has poor binding capacity
- Oxygen contents in mould cavity too high
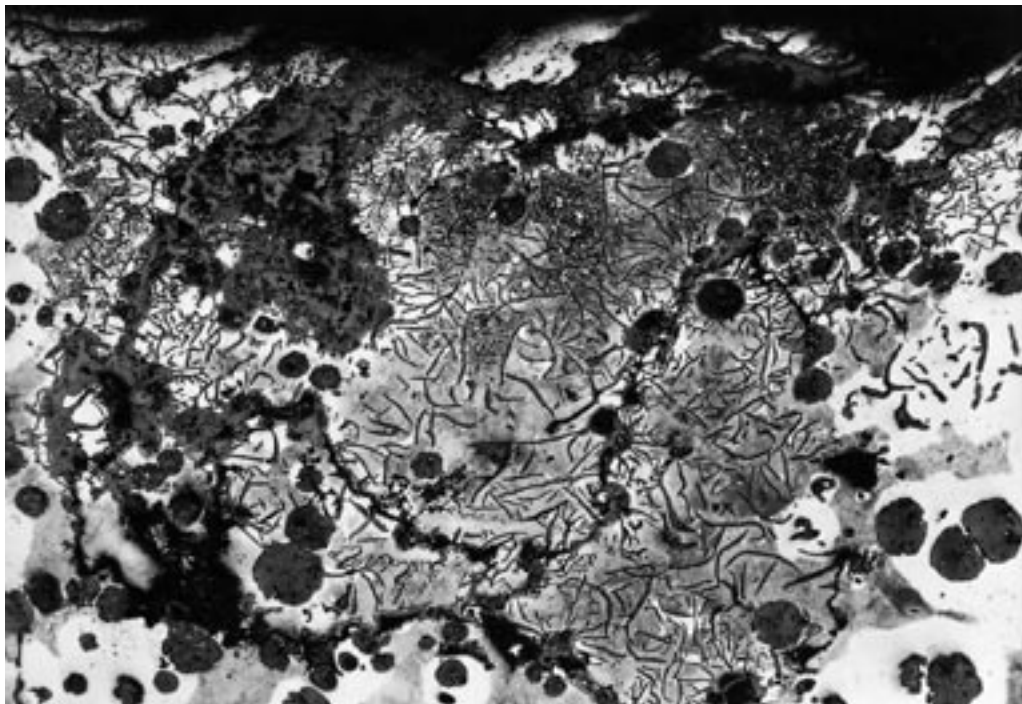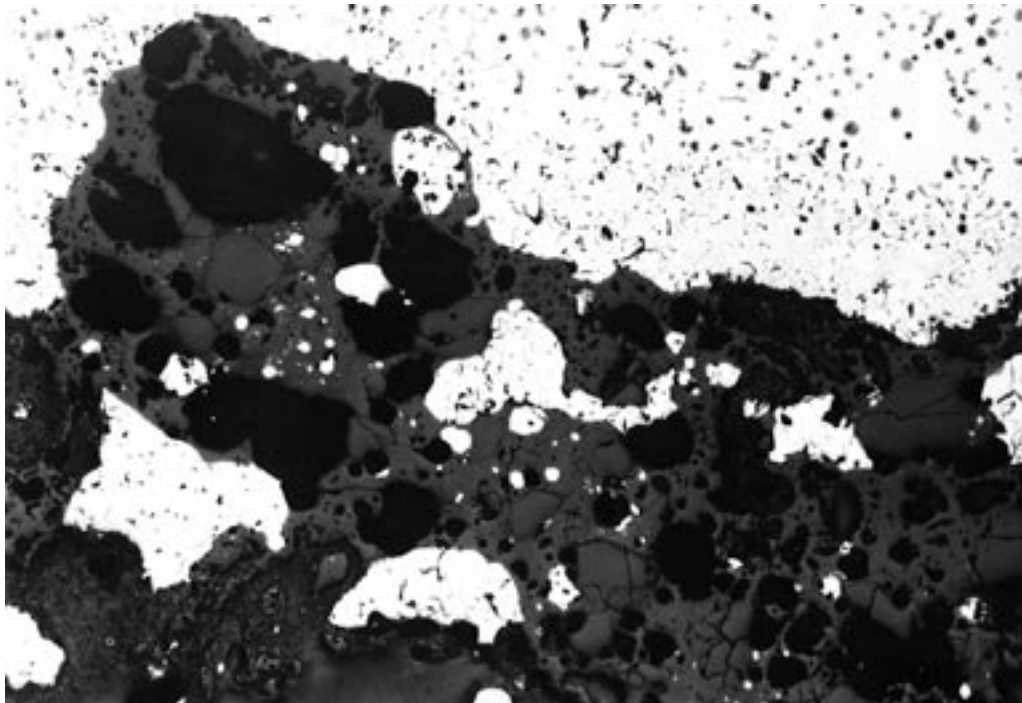- Proportion of low-melting-point compounds too high

Fig. 46:   Micrograph of a slag inclusion in an SG iron casting. Strong reaction of slag accompanied by liberation of gases. Scale: 10 mm ≙ 0.2 mm

Fig. 47:   Micrograph of a slag zone in an SG iron casting. Turbulence and oxidizing atmosphere leads to linear shaped inclusions in the surface area. Scale: 10 mm ≙ 0.08 mm

Remedies

Metallurgical

- Keep contents of elements which strongly react with oxygen as low as possible, e.g. aluminium, magnesium, manganese; if necessary reduce them; use materials without impurities
- Optimize the use of inoculants; avoid slagging; in case of failure to dissolve, reduce grain size
- Dry ladle prior to use; hold molten metal in the ladle for shortest possible time; avoid alloying in the ladle; skim ladles carefully; use slag binders; if necessary use teapot ladles

Gating and pouring practice

- Increase pouring temperature and shorten pouring times
- Improve gating, keep pouring basin full, use slag traps; avoid turbulence when pouring; install strainer core

Clay-bonded sand

- Reduce proportion of inert dust; if necessary add new sand and reduce dust recirculation
- Use bentonites with increased binding capacity and high montmorillonite content – if necessary increase proportion; improve development of bentonite
- Increase lustrous carbon production in the moulding sand or use carbon carriers with higher lustrous carbon producing capacity

Background information

During melting and pouring, many metals react with atmospheric oxygen, whereby alloying elements can accelerate or retard the process.[1] If no complete oxide layers are generated, the quantity of oxidation products will usually increase linearly with time. These processes have been the subject of early studies, principally in relation to non-ferrous metals. In the case of iron-carbon alloys, the process is modified by the creation of carbon monoxide. Solid oxides are only created below the so-called silicon isotherm; these then form into slag because other alloying elements such as iron and manganese also react with the oxygen.[2–4]

$$SiO_{2\,solid} + 2\,C \rightarrow Si + 2\,CO_{gaseous}$$
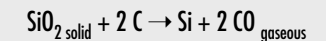
Manganese silicate slag, the melting point of which is lowered by manganese sulphide, plays an important part in the creation of CO-slag pinholes through carbon oxidation (see chapter on pinholes).

The formation of slag can be attributed principally to reactions with atmospheric oxygen.[1] It occurs increasingly when temperatures in the ladle are low. Likewise, oxidation starts earlier if elements with higher affinity to oxygen are present, e.g. aluminium and magnesium.

The longer the time the melt has for oxidation, the stronger is the slagging of the oxides.[2]

As slag can form continuously and increasingly at low temperatures on any iron melt, it is necessary to precipitate the products of the reaction, this taking place in pouring basins and slag separators. Slag is also trapped by dross filters[5] or, more effectively, by strainer cores.[6]

With declining temperatures and an oxidizing atmosphere, oxidation may also occur in the mould cavity, principally through water vapour. This is counteracted by increasing lustrous carbon producing capacity. Furthermore, fines may be loosened from the mould and react with slag containing ferrous or manganese oxide. The proportion of fines should be kept as low as possible.

Inclusions and slag may also occur when using mould inoculants. The inoculation method should be determined accordingly.

The flow of metal into the mould should be laminar. In the event of turbulence, a larger surface area of the molten metal comes into contact with the air / water-vapour mixture and oxidizes, thereby more readily forming slag. Mould filling can be optimized with the aid of simulation programs.

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Fig. 48:   Start of a scab "rat tail" in the upper part of a large-area grey iron casting adjacent to the ingate.
            Scale: 10 mm ≙ 39 mm

Scabbing
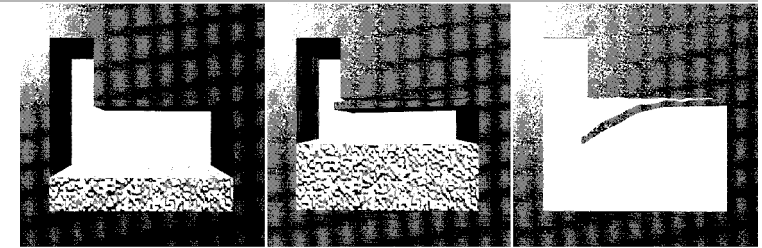
Characteristic features

Irregular, small to large-area solid metallic thickening, frequently several millimetres thick. Such defects often run parallel to the casting surface, their own surfaces being rough. The edges frequently exhibit so-called "undercuts". Castings with solid scabbing often exhibit sand crust inclusions.

Incidence of the defect

Scabs may appear on all casting surfaces when pouring into green sand moulds. They occur primarily at the top of the mould cavity, although their formation on the mould bottom in the form of "rat tails" is likewise possible. Highly compacted parts of the mould cavity are also at risk. Scabs can be created when the mould wall is heated by radiant heat, but may also be caused by the direct flow of heat from the molten metal into the mould wall.

Explanation

During pouring, parts of the sand mould near the surface are heated up rapidly. A dry sand crust a few millimetres thick forms on an over-wetted stratum (condensation zone). As quartz tends to significantly expand at 300°C−575°C, this causes a high compressive stress in the sand crusts which, in the case of poor wet tensile strength in the condensation zone, can lead to them being separated from the stratum.

Possible causes

Clay-bonded sand
- Too little bentonite or poor bentonite quality in the moulding sand
- Proportion of fine quartz in the sand too high
- Moulding sand too fine
- Insufficient conditioning of bentonite
- Degree of chamottization of the sand too low
- Too much salt in the sand

Moulding plant
- Excessive or irregular compaction

Gating and pouring practice
- Sand heated up too severely by inflowing metal and long exposure to radiated heat

Fig. 49:   Scabs on the top part of a large-area grey iron casting.
            Scale: 10 mm ≙ 8 mm

Remedies

Clay-bonded sand

- Increase bentonite content in the moulding sand
- Use bentonite with a higher specific binding power
- Reduce proportion of fine quartz in moulding sand
- Reduce recirculation of dust; if necessary use bentonites with higher montmorillonite content
- Use coarser moulding sand
- Improve conditioning of bentonite; prolong mixing times; pre-wet used sand
- If practical, reduce amount of new sand to increase the degree of chamottization
- Improve water quality; switch from well water to public supplies; perform partial desalination

Moulding plant

- Reduce compaction; reduce compacting pressure
- Ensure even distribution of sand and more uniform compaction of the mould

Gating and pouring practice

- Improve gates to avoid local overheating through excessive amounts of metal
- Aim for shorter pouring times and therefore shorter exposure to radiated heat

Background information

Scabs are typically found on castings from bentonite-bonded sand moulds. The inflowing metal heats the upper surface of a mould. The evaporating water is condensed in underlying layers and weakens the bond in over-wetted regions. At the same time, the compressive stress in the heated sand layers increases through expansion of the quartz. Surface crusts separate.

The tendency for such defects to occur intensifies with increasing compressive stress and declines with increased wet tensile strength.[1] Reference [2] deals with compressive stress and methods of its measurement.

It is known that compressive stress increases with higher packing density of the quartz grains. A dramatic increase takes place when the proportion of fine quartz in the moulding sand is increased.

Wet tensile strength is described in publications [3] and [4] as a parameter for determining susceptibility to scabbing.

The influence of various moulding sand admixtures on the formation of the sand crust has been studied. In general, the risk is reduced by the use of all materials that increase wet tensile strength and lower compressive stress.

Publication [1] examines calcium-type and activated bentonites, wood flour, powdered peat, inert fines and starches as well as carbon dust. Here it was clearly ascertained that the use of soda-activated bentonites markedly reduces susceptibility to scabbing. Another publication [5] emphasizes the impressive reduction in sand crust formation resulting from the addition of carbon carriers with low softening points, which reduce the compressive stresses. Publication [6] reports on the effects of various coal dusts on expansion pressure and wet tensile strength. The study determined an intensified increase in compressive stress when using pit coals with $10-35\%$ volatiles. The stress is reduced by coal mixtures which contain additional carbon carriers with low softening points.

The risk of scab formation when using bentonite-bonded moulding sands can be reduced by increasing the bentonite content, reducing the fine quartz content and using coarser sand. When such defects occur, the degree of mulling of the sand should also be checked. Likewise, too much salt in the water can result in scabbing. In certain cases, such defects could have been avoided by using a partial desalination plant.

Where there is a very high packing density in the mould, a small increase in compactability may counteract the formation of defects.

Likewise, the formation of sand crusts can be avoided by modifying the gating system.

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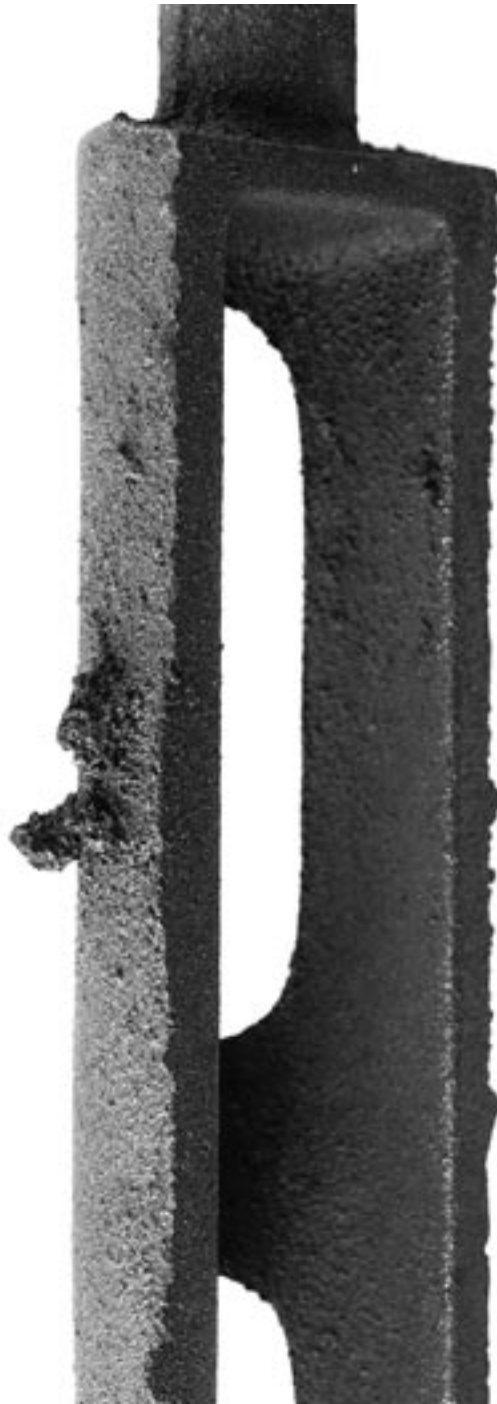Oolithisierung von Formsanden
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Fig. 50:   Grey iron casting. Swollen metal protuberances at very under-compacted areas in the sand mould.
           Scale: 10 mm ≙ 6 mm

Swelling

Characteristic features

Solid thickening on internal and external surfaces as well as edges of castings. Frequently appearing in association with rough casting surface.

Incidence of the defect

The defect may occur principally in areas which have not been optimally compacted. Also, it can often appear in lower sections of the mould. In the case of grey cast iron, swelling may occur as a result of expansion pressure. The defect frequently appears in conjunction with "roughness" and "penetration" defects.

Explanations

If the mould and the core are insufficiently rigid, the mould cavity is expanded by metallostatic pressure. In the case of grey cast iron, the volume is enlarged during solidification. If castings are poured without feeders, the expansion pressure causes an enlargement in volume. The defect may also be caused by movement of the mould side walls (formation of hot crusts).

Possible causes

Moulding plant
- Uneven or poor compaction

Clay-bonded sand
- Compactability too high
- Poor flowability of the sand

Resin-bonded sand
- Insufficient compaction

Metallurgical
- In the case of grey cast iron, expansion pressure too high

Remedies

Moulding plant
- Improve distribution of sand prior to compaction; if necessary, increase pressure; increase tapers on patterns

Clay-bonded sand
- Reduce sand compactability
- Improve flowability of the sand during compaction by using products containing graphite

Resin-bonded sand
- Improve compaction of cores

Metallurgical
- If necessary, reduce the degree of saturation of the iron in order to reduce graphite expansion

Fig. 51:   Large grey iron casting. Thickening at under-compacted positions adjacent to the flask wall.
Scale: 10 mm ≙ 22 mm

Background information

Changes in the dimensions of the mould cavity can be attributed to the pressure of the inflowing metal, the expansion forces of the formed sand crust and, in the case of iron-carbon alloys, the expansion pressure of the graphite. The higher the rigidity of a bentonite-bonded mould and the lower its humidity for a similar compacting energy, the more accurate is its cavity.[1] An authoritative publication confirms that the influence of metallostatic pressure is considerably less than that of graphitization pressure and the expansion force of the moulding material crust.[2] The higher the casting temperature, the greater the pressure on the mould wall. Adding quartz powder has a similar effect, thereby increasing the movement of the mould wall. Circulating sands usually exhibit a greater mould wall movement than new sands. This is probably caused by the higher proportion of quartz dust.[2] Dimensional stability increases with improved compaction and higher strength of binder bridges.[3] Higher bentonite contents lead to increased mould wall movement,[4] the reason for which lies in the lower packing density of the quartz grains.

Additions of organic substances have varying effects on dimensional stability. Wood flour and powdered peat as well as hydrocarbons with a low softening point reduce mould wall movement. This is also true of pit coal if the proportion of volatiles is greater than 20 %. Pit coal dust with 10 − 16 % volatiles increases compressive stress.[2] This is probably because such coals have a minimal softening range. Higher dimensional stability is attained by using various pit coals with differing degrees of milling.[5]

Apart from sand crust expansion leading to mould swelling, poorly compacted areas of the mould are particularly susceptible to expansion defects. The use of sands with high compactability causes risk to cods and sand areas in the vicinity of the flask wall. The use of products containing graphite can markedly improve flowability whilst maintaining compactability. Mould hardness becomes more uniform and improves,[6] thereby reducing swelling.

Swelling may also occur through defects in the mould construction (uneven filling of the sand, poor or uneven compaction).

When using core binders with higher viscosity and higher softening properties, particular attention should be paid to ensuring proper compaction.

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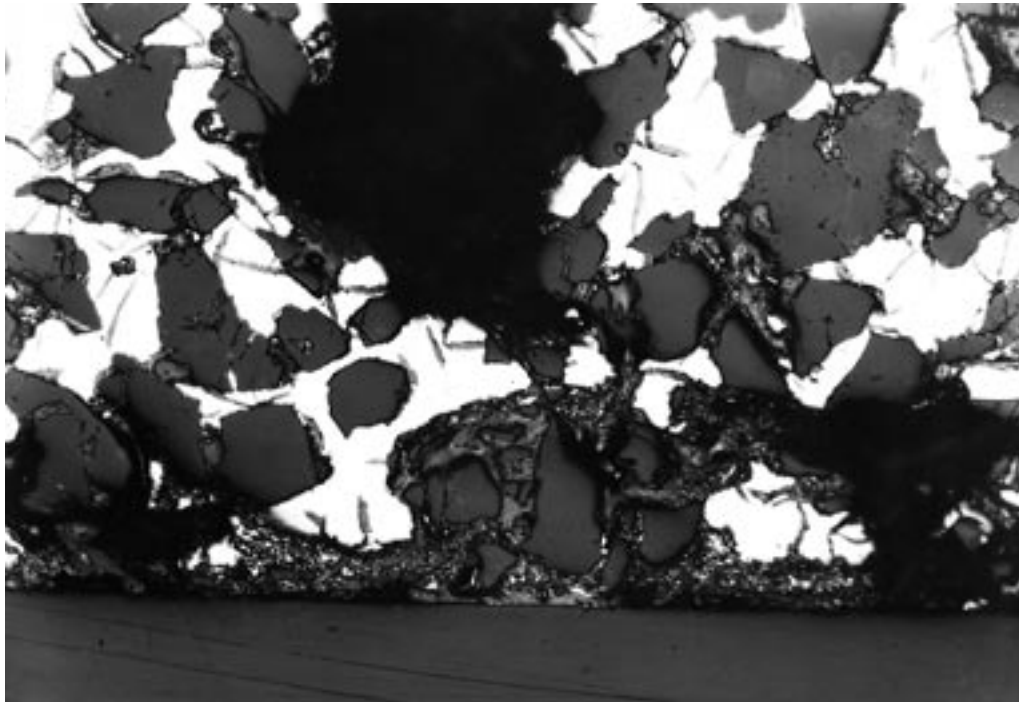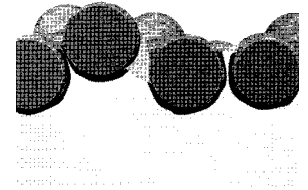Giesserei-Praxis 2, 2000, P. 53 – 62

Fig. 52:   Iron / sand conglomerate firmly adhering to a grey iron casting.
           Scale: 10 mm ≙ 16 mm

Fig. 53:   Micrograph of a layer formed by penetration with chemical reaction in a grey iron casting. The melt / sand reaction
           products are clearly recognizable. Scale: 10 mm ≙ 0.08 mm

Penetration due to chemical reaction

Characteristic features

Firmly adhering conglomerates of sand / metal at hot or poorly compacted positions.

Incidence of the defect

One refers to penetration due to chemical reaction when, as opposed to simple penetration by the molten metal, there is a strong chemical reaction between the metal and the sand grain (fritting, sintering).

A solid conglomerate of metal and sand adheres firmly to the casting. The spots where this defect is likely to occur are edges in the mould or the core where, owing to the geometry of the casting, the metal remains molten for a long time, resulting in extreme heating. Apart from edges, overheated areas of the mould and the core which are poorly compacted are also at risk. The defect occurs more frequently with copper alloys than with iron alloys, on account of the reaction between sand and melt.

Possible causes

Clay-bonded sand
- Compactability of the sand too high
- Moulding sand too coarse
- Sand has a low thermal resistance
- Too little lustrous carbon producer

Moulding plant
- Uneven or poor compaction

Resin-bonded sand
- Sand grains too coarse
- Poor compaction

Gating and pouring practice
- Pouring temperature too high
- Excessive local overheating of mould and core sections
- Metallostatic pressure too high

Remedies

Clay-bonded sand

- Reduce compactability of the sand; this will lead to more uniform and improved compaction
- Make moulding sand finer; if necessary, use finer core sand; use inert fines (coke, etc.)
- Increase temperature resistance of the moulding sand; if necessary, add new sand to reduce oolitization; do not use silica sands containing impurities
- Increase carbon carrier content in moulding sand to increase coke residue and lustrous carbon production; if necessary, use lustrous carbon carriers with higher coke production

Moulding plant

- Improve compaction of moulds; if necessary, increase compacting pressure
- Improve sand filling process to attain more evenly compacted moulds

Resin-bonded sand

- Use finer core sand; compact cores more evenly and effectively
- Dress cores all over or at positions at risk; if necessary, apply dressing of greater thickness; use dressing with low susceptibility to cracking.

Gating and pouring practice

- Reduce pouring temperature and pouring rate
- Improve gating systems in order to avoid local overheating of mould and core sections
- Reduce metallostatic pressure

Background information

The defects "penetration" (physical) and penetration due to chemical reaction cannot be clearly differentiated from each other. The latter is always preceded by physical penetration. In the case of physical penetration, the main effect is the ingress of molten metal owing to metallostatic pressure. Reactions between the melt and moulding sand hardly ever occur. However, with this type of metal penetration, thicker silicate layers form on the sand grains. Due to the reaction between silica sand and melt, the surface tension is markedly reduced; the molten metal permeates deeply into the mould. Small pores are also filled with melt. Hard, firmly adhering conglomerates of sand, slag and metal are formed.

With copper-tin and copper-zinc alloys, penetration due to chemical reaction is triggered by low-melting-point lead components and lead compounds.[1] When casting such alloys using bentonite-bonded sands, enrichment of the lead compounds further promotes reaction of the metal with the sand. Apart from copper alloys, metal penetration frequently occurs during steel casting, principally manganese steels.[2] The manganese oxide slag generated is very aggressive. The use of chromite sand instead of silica sand has been shown to be advantageous.

The defect has also been found in the case of grey cast iron. In principle, the same remedies apply as those employed to prevent physical penetration because the defect begins with ingress of the molten metal or slag into the moulding material.

A finer sand grain size counteracts susceptibility to metal penetration. The addition of fines also has a positive effect. Moulding sands should not contain low-melting-point impurities, because these promote reaction with the slag and the formation of low-melting-point slags. Adding lustrous carbon producers has an advantageous effect because they prevent the formation of reactive oxides and slag. The lustrous carbon generated also prevents wetting of the sand grains.

Metal may also more rapidly penetrate into poorly compacted sand sections, with severe heating leading to reactions with the moulding material and allowing the melt to permeate even deeper.

It is also important to achieve good compaction of cores. Where there is a risk of metal penetration, it is necessary to select a fine sand grain size. Careful dressing is imperative,[3] as metal penetration can occur through small cracks in the dressing.

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