Cracking of grey-iron castings

Types of crack
Much can be learned from the appearance of the crack and its location in the casting. A classification of types of cracking encountered during the manufacture of iron castings is discussed below.

Cold cracks—hairline or closed
This type of crack is often difficult to detect with the naked eye, although it may be subsequently revealed during machining as a thin silvery line. The fractured face of a cold hairline crack will show a normal-coloured grey-iron fracture (unless the casting is chilled). Hairline cracking is almost invariably the result of rough handling at some stage after cooling to ambient temperature.

Cold cracks—opened
A much less common form of cracking is that in which residual casting stresses are partially or wholly a cause of failure. In such cases, the cracks will have opened and will be clearly visible to the naked eye. The extent to which the crack opens when formed (the gap width) is an indication of the level of residual stress that was present in the casting in the cracked area—the wider the gap the higher the stress. A casting that is newly cracked at or near room temperature, with a significant gap formed in the crack, will normally have a clean fracture typical of a grey cast iron.

Hot cracks
These cracks are formed when the casting is hot and may occur when the casting is cooled in the mould, knocked out hot, during cooling after knockout or during heat-treatment cycles. Such cracks are normally clearly visible. Breaking open a casting containing a hot crack will reveal a fracture discoloured by oxidation. With prolonged exposure at high temperature, a thick coating may form on the fractured surfaces, and surface decarburization may occur. It is important to remember that a crack formed in the casting at or near room temperature (a cold crack) will exhibit a discoloured or surface-oxidized fracture if the cracked casting is subjected to a temperature above about 450 °C.

Hot tears
Hot tears rarely occur in grey-iron castings, but can be quite prevalent in white-iron castings. A defect encountered in grey-iron castings that at first sight appears to be a hot tear is often found to be shrinkage porosity, with the subsurface shrinkage cavity just breaking through the casting skin to give the appearance of a hot tear.

Other defects having the appearance of cracks
When cold metal is poured into a mould cavity there is always a risk, particularly in plate type castings, that the leading edge of one stream of metal flowing over the mould face will solidify before merging with a stream of metal flowing from a different direction. This produces a cold lap defect which may sometimes be mistaken for a crack, or it may initiate a crack. Lap defects having the appearance of cracks may sometimes be found in shell-moulded castings, as the result of carbonaceous material from decomposition of resin binders being pushed along with the leading surface of the metal stream, preventing two streams of metal from merging before solidification.
Effect of metal composition

An incorrect metal composition can increase the tendency for cracking to occur by reducing the tensile strength or increasing the brittleness of the iron. Because white iron is more liable to crack than grey iron, the presence of chill at free edges of casting sections greatly increases the risk of cracking. To minimize the risk of chill at free edges, the carbon equivalent of the iron must be correctly specified in relation to casting sections—by preventing the formation of chilled edges, cracking may often be avoided. Chilling may occur in flash, at casting edges, or on core-prints, and cracks occurring in flash can extend or ‘strike back’ into the casting.

To minimize the risk of cracking, the following aspects of metal composition must be controlled.

Minimizing chill

- Sulphur is a potent chill-forming element. This effect should always be neutralized by maintaining an adequate manganese content, in accordance with the formula:
  \[ \text{Mn\% required} = (1.7 \times \text{S\%}) + 0.3 \]
- Unbalanced sulphur can result in the edges or even complete sections of castings being chilled.
- Chromium in amounts up to 0.2 per cent can generally be tolerated, but above this it promotes the formation of chill, particularly in light-section castings. Careful control of this element is necessary, by analytical and chill-testing techniques. Stainless iron or steel scrap containing this, and other elements such as vanadium, tellurium and bismuth which have similar effects, must be rejected.

Dangerous trace elements

- Lead present at levels above 0.0004 per cent (particularly if the iron has picked up hydrogen from damp refractories, ladles or moulds) results in the formation of an undesirable graphite structure in the iron. This structure can seriously weaken the iron and result in cracking of the castings in the foundry, during processing or in service. Lead-bearing materials such as free-cutting steel, automotive-engine scrap, cast-iron scrap carrying thick coatings of lead paint, and lead-bearing non-ferrous components must be excluded from the furnace charge.
- Boron, antimony and lead can be introduced by the inclusion of enamelled scrap in the charge. Higher levels than normal embrittle the iron and increase the tendency of light-section castings to crack. No more than 5 per cent of the charge weight should consist of enamelled scrap.
- Tin is used in some grey-iron castings at levels up to 0.1 per cent to ensure a fully pearlitic matrix. Any excess can reduce the tensile strength, embrittle the iron and increase the risk of cracks occurring.

Cracking due to rough handling

Rough handling is by far the largest single cause of cracking of iron castings.

In highly stressed castings, even a small externally applied force such as a blow from a small hammer can cause fracture (see Fig. 1).

A casting of complicated shape with marked differences in section thickness is likely to contain a significant level of residual stress due to uneven cooling in the mould and may need to be handled with care.

Lack of attention to the following can contribute to cracking problems.

Handling at knockout

- Adhering sand—Hammering to remove adhering sand or to remove cores should be forbidden.
Control the quality of the moulding and core sands to ensure good breakdown. Cores should be poked out when necessary.

- **Runners and risers**—Runners and risers should be designed for easy removal, making use of necked ingates and risers for heavy sections.
- **Flash**—Flash requiring removal by hammering should be prevented by improvement of mould assembly practice.
- **Stacking**—Damage and cracking often result when castings are thrown from the knockout into stillages. Stacking castings in piles can crack those at the bottom of the pile. Stillages should be positioned as close to the knockout as possible, and for light castings they should incorporate racks.
- **Knockout time**—Early knockout can produce warping and cracking. Optimum knockout times should be established for complicated castings that are susceptible to cracking.

**Fettling**

- Removal of flash by hammering or chiselling is a common cause of cracking, particularly if the flash has solidified white.
- Heavy shot-blasting, particularly of light castings, can cause warping and cracking.
- Heavy castings mixed with and falling onto light castings in rotary cleaning units can result in cracking.
- Excess pressure during grinding can overheat casting surfaces and produce cracks, particularly at edges and flanges.

**Handling and transporting**

- **Lifting equipment**—Lack of adequate lifting and lowering equipment may lead to castings being dropped. Plan to minimize movement of castings. Place stillages at convenient positions and plan heights of loading bays to suit lorry platforms. Lower heavy castings onto wooden battens, not concrete floors, when storing between operations.
- **Loading**—Castings should be loaded and unloaded with care, and they should be transported in stillages wherever practicable.
- **Avoid high stacks**—Use stillages and ensure that the load is distributed as evenly as possible through the stillage structure and is not applied heavily on individual castings. Load castings into the stillages by hand or mechanized stacking and not by throwing.
- **Design gravity movement systems to avoid impact of one casting on another.**

**Effect of production method**

There are a number of basic foundry principles, which, if not applied correctly to the production method, will result in cracking of iron castings.

**Faults in the running and gating system:**

- Gating systems that produce uneven heat distribution leading to cooling and contraction differentials.
- Long, single runner bars attached to the casting by a series of short ingates.
- Large common pouring-basins joined to the runner system by two or more downgages.
- Downgates and feeders positioned too close to box bars.
- Very sharp angles between ingates and castings.
Cracking

Restraint from lack of core breakdown:
- Heavy, strong cores surrounded by thin metal sections, which produce insufficient heat to break down the binder.
- The addition of naturally bonded sands to oil sands used for coremaking to give good greenstrength, resulting in poor breakdown properties of the cores.
- CO₂-silicate-bonded sand is susceptible to breakdown problems unless carefully controlled.
- Too many, or incorrectly placed, core grids.

Flash formation:
- Flash around core-prints and mould joints may chill, and cracks in the flash can extend into the casting.
- Heavy flash can impose a serious restriction on the contraction of a casting and result in hot tears or cracks.

Mould or core faults:
- Fins of sand on cores at box or loose-piece joints will produce a notch in the casting and lead to cracking.
- Castings produced ‘thick and thin’ due to bad corelaying or core movement may crack on the thin section, particularly if it is chilled.
- Heavy chaplets coated with lead alloys can have associated areas of degenerate graphite. The degenerate graphite may weaken the iron to such an extent that it is unable to resist the residual stresses and cracking may result.

Cracking of castings in the machine shop

Very substantial stresses can be imposed on iron castings during machining, these stresses often being superimposed on any residual stresses already present in the castings. Most cracks are hairline and can remain undetected during one or more machine operations. It is most important to isolate the stage in the process at which such cracks are being caused and it is frequently necessary to employ a crack detection method such as dye-penetrant or magnetic-particle testing. It may sometimes be necessary to test castings for cracks on delivery from the foundry. If no cracks are found at this stage, then tests should be applied after each successive operation and casting movement until the stage at which the cracking is occurring is discovered. This may be several stages earlier than that at which the cracks have previously been noticed by the naked eye, since fine cracks are not readily observed on rough-machined surfaces.

Common causes of cracking in the machine shop and their prevention are given below.

Rough handling

Cracking by impact can occur during unloading on delivery or during handling of castings onto or off machines. Gravity flow of small castings from one machining operation to another can impose impacts sufficient to cause cracks. See Handling and transporting above.

Clamping of castings for machining

Excessive or uneven clamping pressure applied to castings through chuck jaws is a common cause of cracking, particularly in light sections and when manual tightening of the chuck is applied on
hollow castings. Inadequate or uneven clamping surfaces on casting faces can cause slipping during machining, and hence overtightening to prevent this.

Typical preventive measures:

- Avoid manual over-clamping by using torque-controlled tools.
- Control pneumatic clamping pressures to suit the castings being machined.
- Ensure good contact with the chuck by including clamping-pad surfaces in the design of the casting.

Depth of cut and machining speed

Heavy cuts coupled with high machining speeds can apply sufficiently high stresses to cause cracking in some castings, particularly if the castings already contain significant levels of residual stress. Heavy cuts with high speeds and feeds can be false economies if cracked castings result. The speeds and feeds used should be consistent with the material being machined, the design of casting and the cutting tools employed.

Condition of cutting tools

Higher pressures have to be applied during machining when blunt or incorrectly ground or set tools are employed, thus imposing unnecessarily high stresses on the casting being machined. The risk of cracking is reduced when tools are maintained in good condition and are correctly ground and set for machining the grade of iron being processed.

Interrupted cut

When a cutting tool has to cross a gap or discontinuity in the surface being machined, a high impact load may be applied to the casting when the tool remakes contact with the surface. Repeated impact loading under such conditions can cause cracking of light-section castings, particularly in processes such as high-speed milling or single-point turning.

When interrupted cuts are unavoidable, shallow cuts and lower speeds should be employed.

Grinding operations

Hardened or chilled surfaces on iron castings contain high levels of residual stress and, in the case of chilled surfaces, lower thermal conductivities. The added stresses arising from heat generation during rapid deep grinding, or normal grinding with insufficient flow of coolant lubricant, can cause surface cracking. Shallow cuts and coolants should be used in grinding operations likely to cause surface cracking on iron castings.

Casting design

Castings with essential design features that make them relatively fragile or of a complicated shape that induces significant levels of residual stresses may require special attention. If cracking of such castings in the machine shop is encountered, handling facilities may have to be improved and in the case of highly stressed castings, stress-relief heat treatment prior to machining may be justified.

Every opportunity should be taken to discuss with the customer any feasible casting design modifications that will strengthen sections susceptible to cracking, or reduce residual casting stresses to avoid cracked castings, or reduce the costs involved in stress-relief heat treatment.
Concluding comment

The greatest contribution to the prevention of cracking should come from better supervision and controlling of casting processes and handling procedures. Often, this can be achieved without having to spend money, although in some foundries handling facilities may need to be improved.

Restrictions on the use of hammers and similar implements, reduction of the distances that castings are thrown and dropped, and the prevention of flash on castings are the basic remedies for reducing casting cracking problems in many foundries. A checklist summarizing the main causes of cracking is given below.

Checklist—Cracking of grey iron castings

<table>
<thead>
<tr>
<th>Metal composition</th>
<th>Production conditions leading to high stress</th>
<th>Knockout, fettling &amp; handling</th>
<th>Machining practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low CEV for section thickness causing chill</td>
<td>Faults in running and gating system</td>
<td>Sand, slag, laps and shrinkage acting as stress raisers</td>
<td>Bad handling</td>
</tr>
<tr>
<td>Lead &gt;0.004% can affect graphite and reduce strength</td>
<td>Restraint of strong cores surrounded by thin metal sections</td>
<td>Cracks in flash propagating into the casting</td>
<td>Excessive or uneven clamping</td>
</tr>
<tr>
<td>Tin &gt;0.1% embritles the iron</td>
<td>Fins of sand on cores producing notch effect</td>
<td>Imperfect surface on chills and doseners causing restriction on contraction</td>
<td>Heavy cut and high machining speeds</td>
</tr>
<tr>
<td>Insufficient manganese to balance sulphur (Mn% = 1.75% + 0.3) Sulphur is a potent chill forming element</td>
<td>Differential cooling of thick and thin wall sections producing high stresses</td>
<td>Rapid or uneven heating in stress-relief heat treatment</td>
<td>Poor condition of cutting tools</td>
</tr>
<tr>
<td>Presence of carbide-promoting elements such as chromium</td>
<td>Rapid cooling</td>
<td>Crossed joint causing cracking in thin sections</td>
<td>Heat generation during rapid deep grinding, or insufficient flow of cooling lubricant</td>
</tr>
<tr>
<td>Presence of antimony, boron and lead from enamelled scrap in the charge</td>
<td>Sharp corners and re-entrant angles between sections and at ingate to casting connection</td>
<td>Excessive shot-blasting</td>
<td>Interrupted cut</td>
</tr>
</tbody>
</table>
Fig. 1. Effective strength of casting is reduced by residual internal stress.

Hammering to remove flash as shown on the left-hand casting produced the crack in the right-hand casting.

Cracking in light casting at the sharp re-entrant angle at the ingate junction.

Sand flash at the joint on a small core, and a crack initiated by sand flash. Several sand grains are clearly visible on the wall of the notch.