The effects of the main five elements in cast irons

The levels of the five main elements carbon, silicon, manganese, sulphur and phosphorus in grey, ductile and malleable cast irons have important effects on the castability, structure, and mechanical and physical properties. Additionally, if uncontrolled, they can also promote the formation of certain types of defects and affect machinability. It is therefore important that the effects of these elements are understood and that they are carefully controlled in order that the optimum properties and quality of resultant castings are obtained.

RECOMMENDED FURTHER READING

BCIRA Broadsheet 4: Relation between composition, strength and structure (or hardness) of grey cast iron.
BCIRA Broadsheet 211-7: Effects of carbon in nodular (SG) irons.
BCIRA Broadsheet 211-1: Effects of silicon in nodular iron.
BCIRA Broadsheet 211-3: Effects of manganese in nodular (SG) iron.
BCIRA Broadsheet 211-2: Effects of phosphorus in nodular iron.
BCIRA Broadsheet 6: Subsurface blowholes associated with segregation of manganese sulphide inclusions.
BCIRA Broadsheet 20: Prevention of dross defects in nodular (SG) iron castings.
BCIRA Broadsheet 31: Mis-run castings.
BCIRA Broadsheet 55: Inverse chill in flake graphite cast iron.
BCIRA Broadsheet 64: Cracking in grey iron castings—effect of composition.
BCIRA Broadsheet 162: Importance of controlling low phosphorus contents in grey iron castings.
BCIRA Broadsheet 164-2: Mottle in malleable iron.
BCIRA Broadsheet 164-3: Mottle in malleable iron.
BCIRA Broadsheet 212: Factors influencing the ductile or brittle behaviour of nodular iron.
BCIRA Broadsheet 213: Galvanizing embrittlement of malleable and nodular irons.
BCIRA Broadsheet 214: Temper embrittlement in nodular iron.
BCIRA Broadsheet 223: Factors influencing the ductile or brittle behaviour of malleable irons.
BCIRA Broadsheet 224: Avoiding white iron formation or ‘chill’ in grey irons.
BCIRA Broadsheet 261: Graphite flotation in nodular (SG) iron castings.
Table 1 Grey cast irons.

| Carbon          | Maximum soundness is obtained with a carbon equivalent value (CEV) at 4.3.*
|-----------------|---------------------------------------------------------------------
| (Normal range:  | An increase:
| 2.8–3.7%)       | • Reduces tensile strength and hardness.
|                 | • Increases thermal conductivity.
|                 | • Increases fluidity.
|                 | **High levels:**
|                 | • Promote coarse graphite and open grain on machining.
| Silicon         | An increase:
| (Normal range:  | • Promotes ferrite formation.
| 1.4–2.8%)       | • Reduces strength and hardness.
|                 | • Reduces chilling tendency.
|                 | **Levels above about 2.8%:**
|                 | • Embrittle and harden the iron.
| Manganese       | **Combines with and neutralizes sulphur.**
| (Normal range:  | • When present at levels in accordance with Mn% = 1.7 × S% + 0.3 results in lowest strength and hardness.
| 0.4–0.9%)       | **An increase:**
|                 | • Promotes pearlite.
|                 | **High levels:**
|                 | • Increase the risk of dross and manganese sulphide blowholes.
| Sulphur         | **For effects on hardness and strength see manganese.**
| (Normal range:  | **An increase:**
| 0.02–0.16%)     | • Promote the formation of white irons unless balanced by manganese.
|                 | **High levels:**
|                 | • Promote dross and tendency for manganese sulphide blowholes to occur.
|                 | • Can contribute to inverse chill formation.
|                 | **Low levels less than 0.06%:**
|                 | • Reduce the response to inoculation treatment.
| Phosphorus      | **An increase:**
| (Normal range:  | • Increases hardness and brittleness.
| 0.02–1.2%)?     | • Increases tendency for unsoundness defects to occur.
|                 | • Increases fluidity.
|                 | **Low levels below 0.04%:**
|                 | • Increase metal penetration and finning.
| Carbon equivalent (CE)* | Maximum soundness is obtained with a carbon equivalent value (CEV) at 4.3.
|                 | **An increase:**
|                 | • Reduces tensile strength and hardness.
|                 | • Reduces chilling tendency.
|                 | • Promote coarse structures and open grain on machining.

*Carbon equivalent value (CEV) = C% + Si%/3 + P%/3.
†Although the phosphorus content in some grey cast irons may be as high as 1.2 per cent, levels less than 0.2 per cent are common in high-duty and quality castings, to obtain maximum soundness.
### Table 2 Ductile cast irons.

<table>
<thead>
<tr>
<th>Element</th>
<th>Normal range</th>
<th>Effects</th>
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</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>3.4 - 3.7%</td>
<td><strong>An increase:</strong>&lt;br&gt;• Promotes graphite nodule flotation in hypereutectic irons.&lt;br&gt;• Increases fluidity.&lt;br&gt;<strong>Decreases below 3.5%:</strong>&lt;br&gt;• Adversely affects soundness.</td>
</tr>
<tr>
<td>Silicon</td>
<td>1.8 - 3.0%</td>
<td><strong>An increase:</strong>&lt;br&gt;• Reduces chilling tendency.&lt;br&gt;• Promotes ferrite formation.&lt;br&gt;• Increases hardness and tensile strength of ferritic grades.&lt;br&gt;• Increases ductile-to-brittle transition temperature.&lt;br&gt;• Accelerates pearlite and carbide breakdown during heat treatment.</td>
</tr>
<tr>
<td>Manganese</td>
<td>&lt;0.1 - 0.6%</td>
<td><strong>An increase up to 0.6%:</strong>&lt;br&gt;• Promotes pearlite (mild promoter).&lt;br&gt;• Segregates to cell boundaries and promotes carbides in slow-cooled sections.&lt;br&gt;<strong>Decreases below 0.2%:</strong>&lt;br&gt;• In as-cast ferritic grades, reduces pearlite formation.</td>
</tr>
<tr>
<td>Sulphur</td>
<td>&lt;0.015%</td>
<td>• Excessive levels in base iron increase tendency for gross defects to occur.&lt;br&gt;<strong>Levels above 0.015%:</strong>&lt;br&gt;• Promote the formation of poor graphite nodules and quasi-flake graphite at constant magnesium.</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>&lt;0.05%</td>
<td><strong>An increase above 0.05%:</strong>&lt;br&gt;• Can produce internal unsoundness defects.&lt;br&gt;• Embrittles the iron by raising the ductile-to-brittle transition temperature.&lt;br&gt;• Promotes galvanising and temper embrittlement.&lt;br&gt;• Segregates to cell boundaries and produces carbide/phosphide complexes.</td>
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</tbody>
</table>

### Table 3 Malleable cast irons.

<table>
<thead>
<tr>
<th>Element</th>
<th>Normal range</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>2.4 - 2.6%</td>
<td><strong>Blackheart</strong>&lt;br&gt;<strong>An increase:</strong>&lt;br&gt;• Induces primary graphite formation (mottle), depending on section.&lt;br&gt;<strong>A decrease:</strong>&lt;br&gt;• Promotes hot-tears and shrinkage porosity.</td>
</tr>
<tr>
<td>Silicon</td>
<td>1.2 - 1.6%</td>
<td><strong>Blackheart &amp; whiteheart</strong>&lt;br&gt;<strong>An increase:</strong>&lt;br&gt;• Accelerates carbide breakdown and ferritization.&lt;br&gt;• Promotes primary graphite, depending on section.</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.2 - 0.6%</td>
<td>The effects of sulphur and manganese cannot be considered separately.&lt;br&gt;<strong>Blackheart</strong>&lt;br&gt;• To produce a ferritic matrix, the sulphur must be balanced by manganese.&lt;br&gt;Mn% must be greater than 5% × 1.7.&lt;br&gt;Below this, manganese retards annealability, resulting in retained pearlite and possibly carbides, giving high hardness and low elongation. **Whiteheart**&lt;br&gt;• Excess manganese (5%/Mn% &lt;0.58) promotes a ferritic core structure, loose graphite aggregates, low tensile strength and high ductility.&lt;br&gt;• Excess sulphur (5%/Mn% &gt;0.58) promotes pearlitic core structures, spherulitic graphite, high tensile strength and low ductility.</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.02 - 0.08%</td>
<td><strong>Blackheart &amp; whiteheart</strong>&lt;br&gt;<strong>An increase:</strong>&lt;br&gt;• Increases the ductile-to-brittle transition temperature.&lt;br&gt;• Promotes galvanising and temper embrittlement.&lt;br&gt;• Increases strength.</td>
</tr>
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</table>

*British Standard BS 6681 specifies a maximum phosphorus level of 0.12 per cent, but it is desirable to keep the phosphorus as low as possible because of its effect on the transition temperature.*

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