3. THE FOUNDRY PROCESS

3.1 Overview of metal production processes

A variety of different production processes are used to make metal products, of which casting by the foundry industry is only one branch, as described below.

<table>
<thead>
<tr>
<th>Name/Synonyms</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk ferrous metal production</td>
<td>The production of bulk molten metal from raw ores and metal scrap. The molten metal can then be used for: ♦ continuous casting, ♦ production of billet, plate, sheet, ♦ production of pig iron, ♦ supply to a foundry process.</td>
</tr>
<tr>
<td>&quot;Iron &amp; Steel making&quot;</td>
<td></td>
</tr>
<tr>
<td>&quot;Integrated Steelworks&quot;</td>
<td></td>
</tr>
<tr>
<td>Bulk non-ferrous metal production</td>
<td>The production of non-ferrous metals from raw ores and metal scrap, with refining and purification by chemical, thermal, electrolytic and other methods. Products consist of extruded bar, rod, wire, slab, billet, ingots.</td>
</tr>
<tr>
<td>Refiners/Smelters</td>
<td></td>
</tr>
<tr>
<td>Ferro-alloy and ingot production</td>
<td>Production of certified grades of metal alloys and metal additions (in the form of nuggets, granules, etc.) for use by foundries as raw materials.</td>
</tr>
<tr>
<td>Foundry Casting</td>
<td>Production of &quot;near-net shape&quot; products by pouring molten metal into moulds. The molten metal is produced from scrap, pig iron, ingots and alloys. Associated processes include mould/core preparation and finishing of cast components.</td>
</tr>
<tr>
<td>Forging</td>
<td>Production of dense metal products from ingot or bar stock using heat and pressure.</td>
</tr>
<tr>
<td>Wrought iron working</td>
<td>Commercially pure iron (&gt;99%) worked by hammering, squeezing, rolling or by hand to make high quality or intricate products. Mainly a historical production technique limited to specialty items today.</td>
</tr>
<tr>
<td>Fabrication</td>
<td>Assembly of metal sheet, plate, etc. to make a finished product. May involve cutting, grinding, welding, shaping, etc.</td>
</tr>
<tr>
<td>Machining</td>
<td>Removal of unwanted metal by drilling, cutting, turning, etc. to produce the required shape to the required dimensional tolerance.</td>
</tr>
</tbody>
</table>

Figure 2 below shows the relationship between different ferrous metal production processes. Outputs from some parts of the metals sector serve as raw materials for other parts, while there is also overlap in some of the feedstocks used.
Figure 2. Overview and Relationship of UK Ferrous Metal Production Processes
3.2 Cast metals and foundry products

The metals cast by foundries can be sub-divided into several main groups as shown in Table 4 below.

Table 4. Different Metals used for Casting Production

<table>
<thead>
<tr>
<th>Main Group</th>
<th>Sub-sets</th>
<th>Further divisions and Alloy Constituents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferrous</td>
<td>Iron</td>
<td>Grey: containing &gt; 95% iron with carbon, silicon and manganese. Ductile: iron with carbon, silicon and magnesium. Malleable: constituents as grey iron. Cast in chill condition, graphite aggregated through heat treatment (mainly historic). Alloy: containing up to 30% each of chromium and/or nickel to provide additional hardness and heat-treat ability.</td>
</tr>
<tr>
<td></td>
<td>Steel</td>
<td>Carbon steel: contains carbon levels up to 1.7% (typically 0.1 to 0.5%) and manganese up to 1.6%. Low alloy steel: a low carbon (0.35% maximum) iron alloy containing 3 to 5% chromium and 2 to 8% nickel. Stainless steel: iron base alloy containing up to 30% chromium and/or up to 40% nickel. Corrosion resistance increases with Cr/Ni content.</td>
</tr>
<tr>
<td></td>
<td>Aluminium</td>
<td>Various alloys usually containing silicon, copper and/or magnesium.</td>
</tr>
<tr>
<td></td>
<td>Copper</td>
<td>Pure copper: &gt; 99% pure Brass: an alloy of copper and zinc (up to 45%), sometimes with up to 2% lead and 1% tin. Bronze: an alloy of copper and tin (up to 12%). Variations: leaded bronze (9 to 22% lead), gun metal (3 to 5% lead &amp; 2 to 8% zinc), aluminium bronze (with 6 to 9% aluminium, 0 to 5% nickel, 0.5 to 5% iron), phosphor bronze.</td>
</tr>
<tr>
<td></td>
<td>Zinc</td>
<td>Zinc-based alloys with up to 4% aluminium and trace amounts of copper, magnesium, etc.</td>
</tr>
<tr>
<td></td>
<td>Super alloys</td>
<td>Nickel or cobalt-based alloys in combination with chromium, iron, manganese, molybdenum, etc.</td>
</tr>
<tr>
<td></td>
<td>Magnesium</td>
<td>Magnesium alloyed with aluminium, zinc and thorium. Other metals can be added in trace amounts.</td>
</tr>
<tr>
<td></td>
<td>Titanium</td>
<td>Pure titanium: &gt; 99% pure α/β alloys with aluminium, vanadium, zinc, molybdenum and zirconium.</td>
</tr>
</tbody>
</table>
Foundry castings are required for a wide range of uses and range in size from components weighing a few grams to castings produced for ships and off-shore oil rigs, which can weigh up to 300 tonnes. An overview of some of the products produced is given below.

**Automotive Parts:**
- 31% of UK casting output is for passenger vehicles.
- 18% is produced for commercial vehicles.

![Ductile iron automotive steering knuckle (courtesy of William Lee Ltd.)](image)

![Ductile iron crankshaft (courtesy of ThyssenKrupp Darcast Ltd.)](image)

**Engineering applications:**
- 26% of castings produced in the UK.
- Includes energy production, mining, shipping, rail and pipes.

![Aluminium nickel bronze propeller](image)

![Steel casing for a nuclear power plant (courtesy of Sheffield Forgemasters Engineering Ltd.)](image)
3. The Foundry Process

Telecommunications, leisure and household items:
- golf clubs
- mobile phone casings
- taps, plumbing fittings
- door handles
- components in domestic appliances

Medical implants:
- Femoral hip stems
- Femoral & tibial knee components
- Shoulder, elbow & wrist components
- Surgical staples

Architectural and street furniture:
- lamp posts, benches, railings
- building components
3.3 **Description of the foundry process**

Foundries produce castings that are close to the final product shape, i.e., “near-net shape” components. Castings are produced by pouring molten metal into moulds, with cores used to create hollow internal sections. After the metal has cooled sufficiently, the casting is separated from the mould and undergoes cleaning and finishing techniques as appropriate.

There are a number of documents in the public domain that provide detailed descriptions of foundry processes (Defra 2003a, b; European Commission 2004; Chartered Institute of Environmental Health 1997). A brief description of foundry processes is provided below for those who may not be familiar with the industry.

The production process involves a number of steps as shown below. Technical terms are explained in the following text and the Glossary of Foundry Terms (at the end of the guide).

![Flow Chart of a Typical Foundry Process](image-url)
3.3.1 Pattern making

Patterns provide the exterior (mould) or interior (core) shape of the finished casting and are produced in wood, metal or resin for use in sand mould and core making. Patterns are usually made in two halves.

Figure 4. Final painting of a pattern half for a pump casing

3.3.2 Sand mould and core making

Sand casting is the most common production technique, especially for ferrous castings. Sand is mixed with clay and water or with chemical binders and then packed or rammed around the pattern to form a mould half. The two halves are joined together to make the mould - a rigid cavity that provides the required shape for the casting, as shown in Fig. 6 below.

Variations on this technique include the use of plaster in place of sand and the recently invented Patternless® process (CDC 2000), where the mould is machined directly out of a sand block without the need for a pattern.

Cores are produced by blowing, ramming or in heated processes, investing sand into a core box. The finished cores, which can be solid or hollow, are inserted into the mould to provide the internal cavities of the casting before the mould halves are joined. Sand cores are also widely used in die-casting, where permanent metal moulds are employed.

Figure 5. Sand mould half for a wing hinge rib for the Airbus A380

Figure 6. Assembled Mould with Core Inserted Ready for Casting
3.3.3 Other casting techniques

Although sand casting is the predominant production technique, other methods are used, as described below. The proportions of the various techniques used in the UK are shown in Figure 7.

Metal moulds are used for certain types of production including centrifugal casting techniques and die-casting. Centrifugal (spun) casting involves pouring the metal into a rotating mould and is used for making pipes, rolls and cylinder liners. Die-casting is commonly used for production of aluminium and zinc castings.

For investment and Replicast® (Ashton 2002) processes, expendable pattern replicas are made in wax or polystyrene and then coated with a ceramic refractory material to make a hard shell. Wax is removed from the shell by steam and polystyrene removed by firing. The shell is then fired at 1000°C to set the ceramic bond. For casting, the shells are sometimes embedded in vacuum packed or chemically bonded sand to provide support and enable a thinner shell to be employed.

Lost foam casting is another variation involving the use of polystyrene pattern replicas. In this process, the pattern replica is coated with a single coat of refractory paint and embedded in a box of sand, which can be chemically bonded or stiffened by vacuum. The molten metal is poured directly onto the replica resulting in vaporisation of the polystyrene.

3.3.4 Metal melting

Molten metal is prepared in a variety of furnaces, the choice of which is determined by the quality, quantity and throughput required.

- **Electric induction furnaces** are the most common type used for batch melting of ferrous, copper and super alloys. This method involves the use of an electrical current surrounding a crucible that holds the metal charge. Furnace sizes range from <100 kg up to 15 tonnes. For production of super alloys and titanium, melting may be undertaken in a vacuum chamber to prevent oxidation.

- **Cupolas** are used solely by iron foundries for continuous production of molten iron. The cupola consists of a shaft in which a coke bed is established. Metal, coke and limestone are alternately charged into the furnace from the top. Molten metal trickles through the coke bed picking up essential carbon, while impurities react with the limestone to form waste slag. Both metal and slag are continuously tapped out at the bottom. Metal throughputs of 1 to 45 tonnes per hour are achieved in the UK.

- **Electric arc furnaces** are still used by a few ferrous foundries in the UK, mainly producing steel castings, although most have been replaced by induction furnaces. Furnaces of 3 to 100 tonnes capacity are in use in the UK. The design involves the use of a holding bath into which electrodes are inserted. The heat generated by creating a charge between the electrodes causes the metal to melt.
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- **Rotary furnaces** are relatively uncommon in the UK but are used in some iron foundries. The furnace consists of a horizontal cylindrical steel shell mounted on rollers and lined with refractory material. The furnace is fired using gas or oil from one end and the furnace body is slowly rotated during melting.

- **Gas-fired shaft and resistance furnaces** are used for melting of aluminium. Shaft furnaces provide a continuous melting and tapping capability, useful at high production facilities. Resistance furnaces are employed for melting of small batches.

- **Gas and oil-fired crucible furnaces** are used for small batch melting of copper and aluminium alloys, although oil-fired units are less common now and tend to be limited to smaller foundries. Unlike the larger furnaces where molten metal is tapped into a ladle for casting, the crucible is lifted out (or pops out) of the heating chamber and the molten metal can be poured directly into the mould.

### 3.3.5 Casting and separation

Molten metal is poured into moulds using various types of ladles, or in high volume production, automated pouring furnaces. Metal is poured into the “runner” (a channel into the mould cavity) until the runner bush is full. The “riser” provides an additional reservoir of feed metal to counteract the shrinkage that occurs as the casting begins to cool.

![Figure 8. Casting a Sand Mould](image)

When the metal has cooled sufficiently for the casting to hold its shape, it is separated from the mould by mechanical or manual methods. Where sand moulds are used, the process is often referred to as shakeout or knockout, and large amounts of dust may be generated.
3.3.6 Removal of runners and risers

After casting, these extraneous pieces of metal are removed and often collected for re-melting. In ferrous castings and larger non-ferrous castings, they may be removed by knocking off, sawing or cutting using an arc air or oxy-propane torch. In die-castings, they are often snapped off manually.

![Figure 9. Casting after knockout with runners & risers still attached](image)

3.3.7 Finishing

A range of finishing processes is usually undertaken. These include:

- cleaning to remove residual sand, oxides and surface scale, often by shot or tumble blasting;
- heat treatment, including annealing, tempering, normalising and quenching (in water or oil) to enhance mechanical properties;
- removal of excess metal or surface blemishes, (e.g., flash resulting from incomplete mould closure or burrs left from riser cut-off), by grinding, sawing or arc air (oxy-propane cutting);
- rectification of defects by welding;
- machining;
- non destructive testing to check for defects;
- priming, painting or application of a rust preventative coating.

3.3.8 Sand recovery and reclamation

The industry recycles a large proportion of mould and core making sand internally for re-use. This involves processing to remove tramp metal and returns the sand to a condition that enables it to be used again for mould or core production.