3. EXPERIMENTAL DETAILS

3.1 Introduction

Molding and castings are the integral manufacturing steps in a foundry practice. Castings are manufactured in a foundry with different processing conditions. The quality of casting is mainly dependent on the composition of raw materials and operating conditions. In the present investigation, a large number of cast iron samples are prepared and the operating stages are listed below:

In stage-1, the liquid cast iron melt was poured into the moulds where mild steel chills were placed. This is to understand the solidification characteristics of the cast iron and its influence on mechanical properties. Moreover, the chills have been maintained at room temperature and cryogenic temperature of ~60 °C. In addition, the cast iron melt has been also added with 0.3 wt % Cr to understand influence of alloying element and influence of solidification rate on mechanical properties with and without chills. In stage-2, cast iron melt was poured in the mould where the thickness of the chills was varied. In this experiments, the thickness of the chills were altered to understand the influence of thickness of chill, solidification behavior and its influence on mechanical properties. Moreover, chromium and nickel was added to grey cast iron melt to understand influence of these alloying elements on solidification behavior of cast iron. Similarly, in stage-3, the chill position was varied and it is intended to the study the role of chill position on solidification characteristic of grey cast iron.

3.2 Melting of cast iron

3.2.1 Induction melting

Cast iron melting was carried out in an induction furnace. A core type induction furnace with a 100 kg/ h capacity and a frequency of 1000 cycles/sec was used for melting purpose. The chemical composition is the grey cast alloy is given in Table 3.1.

<table>
<thead>
<tr>
<th>Carbon C</th>
<th>Silicon Si</th>
<th>Manganese Mn</th>
<th>Sulphur S</th>
<th>Phosphorous P</th>
<th>Iron Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2</td>
<td>1.9</td>
<td>0.85</td>
<td>0.052</td>
<td>0.078</td>
<td>Reminder</td>
</tr>
</tbody>
</table>
A wood pattern was prepared for using normal molding practices. Grey cast iron samples with a shrinkage allowance of 0.01 mm/mm and finishing allowance of 3 mm were made. While using the external mild steel chills, provision has been given for inlet and outlet connections, where the liquid nitrogen coolant was sent to control the solidification rate. Provision was also made to measure chill temperature using a chromal-alumel thermocouple and is shown in Fig. 3.1 and Fig. 3.3. Liquid nitrogen was passed using air compressor. A proper inlet and outlet arrangements were made to supply liquid nitrogen. Wooden plug was clamped to the opening of liquid nitrogen cylinder. Air was pumped through the inlet of the cylinder. Liquid nitrogen outlet from the cylinder is connected to the mild steel chill (MSC) inlet and is shown in Fig.3.1, Fig.3.4 and Fig.3.5. Figure 3.1a shows photographic view of liquid nitrogen assembly, nitrogen inlet, outlet and thermocouple used to measure the chill temperature.

![Fig. 3.1a Liquid nitrogen pumping arrangement View-1](image1)

![Fig. 3.1b Liquid nitrogen pumping system View-2](image2)

![Fig. 3.1c Chills used under cryogenic condition](image3)

![Fig. 3.2 Pattern used for casting](image4)

In the present work, green sand hand molding technique was used to prepare the mold cavity. The mould was prepared with the composition of molding sand, bentonite etc. and
was shown in Table 3.2. Mold cavity was prepared using the wood pattern and was shown in Fig. 3.2.

Chilling effect has been created by using external chill and is shown in Fig. 3.3 and Fig. 3.4. Fig. 3.3 shows the schematic diagram showing chill, chill position, mould block and gating system. Liquid nitrogen was allowed to pass through the chill till the steady state is reached. After this, cast iron molten metal was poured in the mold. Liquid metal from the furnace was transferred through the ladle. Silicon and chromium are added to the cast iron molten metal as inoculants and stirred for required time. Cast iron molten metal was poured into the cavity through the sprue and is shown in Fig. 3.3 and Fig. 3.5. Chromium up to 0.3% was added to grey cast iron melt as inoculant. Samples are made with various processing conditions viz: using MS chill, without chill, by adding chromium, without chromium, chill temperature etc.

![Schematic diagram showing chill and gating system-stage-1](image)

**Table 3.2 Main Composition of molding sand-stage-1**

<table>
<thead>
<tr>
<th></th>
<th>Sand</th>
<th>Moisture</th>
<th>Binder</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>60% lake sand, AFS 100, 40% reclaim sand</td>
<td>4%</td>
<td>Bentonite 2.5%</td>
</tr>
</tbody>
</table>
3.2.2 Cupola melting

Cast iron ingots were produced using a cupola furnace with the chemical composition mentioned in Table 3.3.

![Fig. 3.4 Mild Steel Chill in drag](image1)

![Fig. 3.5 Set up for pouring of molten metal in mold](image2)

**Table 3.3 Chemical Composition of castings-stage-2 (wt %)**

<table>
<thead>
<tr>
<th>Element</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>S</th>
<th>P</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.4</td>
<td>2.0</td>
<td>0.9</td>
<td>0.05</td>
<td>0.075</td>
<td>Reminder</td>
</tr>
</tbody>
</table>

A teak wood pattern was made with a finishing allowance of 3 mm. Mild steel chills with various thicknesses were prepared (Fig. 3.6). Cast iron scrap along with pig iron was melted in a cupola furnace. The later has a melting capacity of 1 ton, 750 mm as inner dia and height of 5 meters with 100 mm thick firebrick lining. Mild steel shell of 8 mm thickness was used for cupola construction.

Chilling effect has been created by using external chills and is shown in Fig. 3.6 and Fig. 3.7. Liquid metal from the furnace was transferred through the ladle. Inoculants like silicon, chromium and nickel are added to the molten cast iron metal and stirred. Molten metal was poured into the cavity through the sprue and is shown in Fig. 3.7. Skim bob was provided near to the sprue to filter the molten metal from slag and other impurities. Fig. 3.7 shows the photograph of cast ingot with sprue, skim bob and riser. Figure 3.8 shows the schematic diagram showing chill, chill position and gating system. Casting ingots were prepared by adding chromium and nickel from ~0 to 2.0 %. In the present work, green sand hand molding technique was adopted to prepare the mold cavity. The mold was prepared with the composition of molding sand, bentonite and is shown in Table 3.4. Fig. 3.6 shows the cupola, pouring of molten metal through ladle, MS chills of various thickness, mold cavity
preparation using pattern, chill and part of gating system. Fig. 3.7 shows mould cavity, metal pouring with air blower and casting ingot with returns like sprue, runner, skim bob and riser.

<table>
<thead>
<tr>
<th>Sand</th>
<th>Moisture</th>
<th>Binder</th>
</tr>
</thead>
<tbody>
<tr>
<td>60% lake sand, AFS 100, 40% reclaim sand</td>
<td>4%</td>
<td>Bentonite 2.5%</td>
</tr>
</tbody>
</table>

Table 3.4 Main Composition of molding sand-satge-2 and 3

Fig. 3.6 MS Chills of various chill thickness and pattern position.

Fig. 3.7 Mold cavity and cast product showing sprue and riser.
Cast iron ingots are produced using a cupola furnace and chemical composition is shown in Table 3.5 (stage-3). Mild steel chill (MSC) were used and placed at different locations. Fig. 3.9 showed the schematic diagram of mild steel chill, chill position and gating system. Casting manufactured with various conditions is shown in Table 3.6. The composition of molding sand, bentonite used for making a mould is shown in Table 3.4. Mould cavity was prepared using the pattern and is shown in Fig. 3.6 and Fig. 3.7. Chill were located at the end parallel and perpendicular to the molten metal flow. Table 3.6 shows the various alloys and the location of the MS chill.

### Table 3.5 Chemical Composition of castings-stage-3 (wt %)

<table>
<thead>
<tr>
<th>Alloy</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>S</th>
<th>P</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alloys-17 to 21</td>
<td>2.8</td>
<td>2.0</td>
<td>0.85</td>
<td>0.052</td>
<td>0.078</td>
<td>Reminder</td>
</tr>
</tbody>
</table>
In Table 3.6, chill positions is shown for producing alloys-17 to 21. Alloy-17 is produced without placing MS chill. Only side chill is placed to manufacture the ingot and named as alloy-18. Chill position is change for producing alloy-19. Only bottom chill is place at the bottom for producing alloy-19.

Only one ingot is manufactured by placing the side and bottom chill simultaneously. Both the chills are of 30x25 mm\(^2\) cross sectional area with ~130 mm in length. Alloy-20 is named for the bottom zone surface of the common ingot produced using side and bottom MS chill. Alloy-21 is the reference of bottom surface as mentioned in Table 3.6. Arrow heads shows in Table 3.6 are the reference surfaces used for hardness test and microstructural examination.
<table>
<thead>
<tr>
<th>Alloy</th>
<th>Chill Position</th>
<th>Castings are produced with respect to chill location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alloy-17</td>
<td>No Chill</td>
<td>CASTING</td>
</tr>
<tr>
<td>Alloy-18</td>
<td>Side Chill</td>
<td>CASTING</td>
</tr>
<tr>
<td>Alloy-19</td>
<td>Bottom Chill</td>
<td>CASTING</td>
</tr>
<tr>
<td>Alloy-20</td>
<td>Side surface</td>
<td>CASTING</td>
</tr>
<tr>
<td>Alloy-21</td>
<td>Bottom surface</td>
<td>CASTING</td>
</tr>
</tbody>
</table>

Chill and casting size

CASTING (25x100x150mm)
3.3 Sample preparation

The grey cast iron ingots were machined in steps and samples with required dimensions were made. Machining operations such as surface milling, surface grinding and sawing were performed. A grey cast iron ingot was machined using vertical milling machine and is shown in Fig. 3.10a. Cast ingot was clamped using machine vice. The surface of the ingot was milled to get a flat surface using shell milling cutter. To get the flat surface on all faces, 1.5-2 mm material was removed. Care was taken using water based and / or oil coolant to avoid temperature rise during machining. Chilled and other surfaces were punched or scribed at specific locations for identification purpose.

Surface grinding was performed using surface grinder to give the fine finishing. Very small quantity of the material was removed in steps, a continuous automated supply of coolant was maintained to prevent thermal stresses, and temperature rise during grinding operation. A small amount of material was removed (0.02 to 0.04 mm). A total of 0.2 to 0.5 mm was machined depending on the surface condition of the cast material. Surface grinding set up for the experiments is shown in Fig. 3.10b. Safety precaution was taken while grinding. Automatic cross and transverse feed was set after giving small depth of cut. The material was clamped such a way that the chilled portion to be machined (sawing) at the end for effective sawing. Chill end of the cast ingot is shown in Fig. 3.10c (shows as arrow head). A care was also taken to supply the coolant and clamp the work piece firmly.

The samples were finally made to desired surface condition for hardness, compression, impact and wear tests. Samples for microstructural examination was also prepared by selecting the chilled face (F), middle face (M) and back face (B) and is shown in Fig. 3.11a and b.

Few samples are reused after optical microscopic examination. Again samples are prepared to desired conditions for high magnification images through scanning electron microscope.
a. Surface Milling  
b. Surface grinding  
c. Sawing  
d. Material for Sample preparation

Fig. 3.10 Sample preparation using machine tools

Fig. 3.11a Cast ingot showing chilled face (F), M and back face (B)
3.3.1 Hardness test

In Vickers hardness test, a small diamond pyramid indenter with an angle of 136° was indented on to the test sample at a predetermined load. Load is applied by hydraulic system through a push button. The indentation is projected on to a screen. The screen assembly consist of graduated frosted glass and graduated plain glass. The two scales slides on each other with a vernier scale. The measuring device can be turned to 360°, which can measure in both axis from tip to tip. The average of the two axis measurements is then converted into a Vickers Hardness number. Vickers hardness test equipment was supplied by Fine spavy associates and engineers (P) limited, Miraj (Maharashtra). A BV-120 model was used for all hardness tests. The machine confirms to British standard BS: 891 and Indian standard IS: 3804-1988. ASTM E92 standard is selected for testing metallic materials. Samples were metallographically prepared for hardness measurement. A load of 30 kgf is selected for considering the accuracy of image and measurement limitation. Image diagonals (tip to tip) are measured to an accuracy of ±0.005 mm. Sample image of the indentation using Vickers hardness tester is shown in Fig. 3.12.
3.3.2 Compression test

Samples were subjected to compression test using a universal test machine, model TUE 400, supplied by Fine spavy associates and engineers (P) limited, Miraj (Maharashtra). The machine was supplied as per IS 1828-1991 requirements. Compression test is accomplished by subjecting a test material to axial loading which produces crushing action. This results in compression of the specimen. A ratio of length to width of 2 is commonly employed in order to prevent the specimen failing by buckling. Large lateral deformations are not produced in brittle material and it commonly ruptures either along a diagonal plane or with a cone or a pyramidal shaped fracture. The modulus of elasticity and yield strength for ductile metals are approximately equal in compression and tension, whereas for brittle materials the yield strength / ultimate strength in compression is greater than in tension.

Samples for compression test were prepared for a size of ~10 mm x 10 mm x 20 mm as shown in Fig. 3.13. Sample surface was machined using milling machine to prepare it for compression test. Surface grinding on few samples is performed to shape the material to required size. 10x10 mm square end surface is placed on the lower jaw. Movable jaw is moved through the hydraulic arrangement by operating various hydraulic valves. Load is applied gradually till the specimen reach its ultimate load carrying capacity. Fig. 3.13 shows the samples tested for compression on universal testing machine.
3.3.3 Impact test

Impact test is used to measure the materials ability to withstand shock loads. The impact test is carried out on a pendulum type impact testing machine of model FIT-300 (N), supplied by Fine testing machinery, Miraj (Maharashtra). The test equipment is consisting of a moving mass, where kinetic energy is high enough to rupture the test specimen. It also has an anvil and a support on which the specimen is placed to receive the blow. Fracture energy of the specimen is measured after the sample is broken. Impact test samples were prepared as per ASTM A370. Samples of 10 x 10 x 55 mm$^3$ with V-notch were prepared for charpy test. Angle of 45° was made with HSS cutting tool and bevel protractor was used to check the angle (as shown in Fig. 3.14a). V-notch was machined using shaper at an angle of 45° and 2 mm deep. Angle and depth of the notch was inspected by using profile projector. The notch angle and depth are finished to an accuracy of 45°±0.5° and ± 0.1 mm respectively. Sample prepared for charpy test and inspection of notch is shown in Figs. 3.14b and 3.14c, respectively.
3.3.4 Sliding wear test

Sliding wear test is performed on the grey cast iron samples using pin on disc wear test machine (model TR–20LE–PHM–200) and is supplied by DUCOM, Bangalore. The equipment complies with ASTM G99 standard. This machine represents a substantial advance in terms of simplicity and convenience of operation, ease of specimen clamping and accuracy of measurements, both of wear and frictional force. The equipment is designed to apply varying load and speed. This apparatus facilitates study of friction and wear characteristics in sliding contacts under different test conditions, sliding occurs between the stationary pin and rotating disc. The normal load, rotational speed and wear track diameter can be varied to suit test conditions. Tangential frictional force and wear are monitored with electronic sensors and are recorded using a computer. These parameters are available as functions of load and speed. Sliding wear test determines the wear and co-efficient of friction of metals under sliding contact. The tester is operated with a pin positioned perpendicular to the flat circular hardened die steel disc. The test machine causes the disc specimen to revolve about the disc center, and the sliding path is a circle on the disc surface. The outer surface was coated with WC-12 Co since the hardness of the cast iron samples is high as compared to the hardened die steel counter surface.

Samples of 6 mm dia x 50 mm height and 8 mm dia x 40 mm height were prepared to understand the sliding wear behavior of cast iron using pin and disc method. Samples, steel disc, tungsten carbide coated disc and wear machine set up are shown in Fig. 3.15a,b,c,d. Care was taken to provide smooth finish to testing surface (contact surface) of the sample.
using lathe, carbide turning cutter and fine abrasive paper. Wear test machine and its technical contents are shown below as Figs. 3.15a - d.

![Wear test samples of 6mm dia](image1)
(a) Wear test samples of 6mm dia

![Tungsten carbide (WC) disc and hardened steel disc](image2)
(b) Tungsten carbide (WC) disc and hardened steel disc

![Wear testing showing pin and WC disc](image3)
(c) Wear testing showing pin and WC disc

![Pin and disc set up with data acquisition system with PC](image4)
(d) Pin and disc set up with data acquisition system with PC

Fig. 3.15 Wear test samples, disc and machine set up

### 3.3.5 Microstructural evaluation using a metallurgical microscope

Sample for metallography examination were initially grinded and surface was made as flat. Further polishing was done using 240, 600, 800, 1000 and 2000 grit emery papers. Samples were prepared to remove the scratches by rubbing the measuring flat surfaces in stages. Alumina and diamond pastes were used for polishing to get the required mirror finishing. Measuring surfaces were polished using velvet cloth with alumina powder mixed with water and diamond paste is shown in Figs. 3.16 a-c. Polished samples were etched using picral reagent (ethanol-96 ml, picric acid- 4 ml) for 20-30 sec. Metallurgical microscope (Met scope - T1600), with image analysing software is used for quantitative analysis.

### 3.3.6 Samples observed using scanning electron microscope

For SEM studies, all samples are initially prepared as per the procedure mentioned in section 3.3.5. Selected samples that were observed using metallurgical microscope are taken
for further microstructural studies using SEM (Fig. 3.17). Polished surfaces were etched for 30-40 sec using nital as etchant (1.5% HNO₃ and alcohol). Samples are observed using SEM (model ESEM Quanta 200). Large size samples were mounted using bakelite powder and coated with gold to retain conductivity. Small samples are directly loaded in SEM for detailed microstructural studies.

Fig. 3.16  (a) Polishing of the Sample using alumina powder of grade A,B,C and diamond paste  
(b) Sample mounted on a metallurgical microscope and (c) Samples prepared for microstructural study
Based on the experimental set up, it was clearly understood to prepare the samples for mechanical and sliding wear test. Moreover, samples are professional prepared for microstructural examination for optical images using metallurgical microscope and high magnification images with the help of scanning electron microscope (SEM). This enables to understand the scientific principles for formulating the research work. The results obtained by various techniques are analyzed and explained in chapter-4.