CHAPTER – III

MATERIALS UNDER STUDY
CHAPTER-III

3.0 MATERIALS UNDER STUDY

3.1 Zinc-aluminium alloy

The present study is on zinc-aluminium alloy (ZA-27) with garnet (Mineral Almandine) as the reinforcement. Zinc-aluminium alloys 8, 12 and 27 comprise a new family of zinc casting alloys that have proven themselves in a wide variety of demanding applications. They are engineering materials well suited to applications requiring high strength, hardness and wear resistance. These zinc-aluminium alloys offer designers and casting specifiers viable, cost-effective alternatives for their component requirements.

The alloys are designated 8, 12 and 27 because of their approximate aluminium content. Each alloy contains copper and magnesium to provide an optimum combination of properties, stability and castability. Widespread commercial acceptance of these alloys has resulted in the issuing of national and international standards, notably, ASTM B 669-95. The chemical composition of zinc-aluminium alloy-27 is shown in table 3.1

<table>
<thead>
<tr>
<th>Composition</th>
<th>Al</th>
<th>Mg</th>
<th>Cu</th>
<th>Fe</th>
<th>Pb</th>
<th>Sn</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>% by weight</td>
<td>25.0-30.0</td>
<td>0.012-0.020</td>
<td>2.0-2.5</td>
<td>0.075</td>
<td>0.006</td>
<td>0.003</td>
<td>Balance</td>
</tr>
</tbody>
</table>

Zinc-aluminium alloys have several advantages over other commonly used casting alloys based on iron, aluminium or copper.

These alloys have better machinability, can be cast to closer tolerances and have a superior as-cast surface finish when compared to cast iron. They are
generally better suited for short production runs and less likely to require protective finishes. These advantages have resulted in substantially reduced production costs for numerous applications.

Zinc alloys are harder and stronger, machine more easily, have superior pressure tightness, and have substantially better wear and bearing characteristics when compared with aluminium [97]. Also, alloys 8 and 12 are not subject to incentive sparking. The alloys become viable choices when aluminium is inadequate in one of these areas. Although they are more expensive on a unit volume basis, castings are potentially cost competitive when aluminium castings require heat treatment, hard anodizing, epoxy impregnation, or bronze bushing inserts.

The most expensive of the common foundry alloys, the lower inherent cost of the zinc alloys combined with their lower densities can result in a material cost saving of up to 60 percent when compared to copper. They also have higher as-cast strength and hardness, and equivalent or superior machinability and wear resistance.

3.2 Foundry practice with zinc-aluminium alloys

Zinc-aluminium-27 (ZA-27) alloys are readily melted in refractory-lined or non-metallic crucible furnaces similar to those used for other non-ferrous foundry alloys. In general, it is recommended that a separate crucible be reserved for melting because of the low impurity limits specified for the alloys. Crucibles have to be thoroughly cleaned for every process.

The zinc alloys melt in less time and do not require fluxing or degassing as is common with aluminium alloys. Melting the alloys produces no fumes and the relatively low casting temperatures, 450-600°C help to extend the service life of
foundry equipment [98]. The normal foundry practice of blending foundry returns with fresh ingots is recommended.

**Casting:** The zinc alloys have excellent mould filling characteristics and low casting temperatures compared to most other foundry alloys. These inherent properties account for fewer casting rejects, reduced metal losses, and good casting fluidity of the alloys. They can be cast using all the traditional processes including sand, permanent mould, pressure die, shell and investment casting.

**Permanent mould casting:** Alloys 8 and 12 are recommended for permanent mould casting, with alloy 8 offering faster cycle times and a better surface for applying decorative plated finishes. Compared to alloy 8, alloy 12 castings have superior strength, hardness, wear resistance and dimensional stability. Both alloys have very good fluidity which permits casting of thin, intricate sections without misruns. In general, ferrous permanent moulds designed for aluminium are suitable for casting zinc alloys.

**Pressure die casting.** When die cast, alloys 8, 12 and 27 provide substantial property improvements over conventional zinc and aluminium die casting alloys. The improved strength and wear characteristics of these alloys allow this highly economical process to be selected for applications where the traditional die casting alloys would not be considered. Alloy 8 can be cast in the hot chamber process commonly used with conventional zinc die casting alloys. Alloys 12 and 27 must be cast using the cold chamber process. The life of iron components in the hot chamber process would be unacceptably short at the required casting temperatures for alloys 12 and 27 [99,100].
3.2.1 Advantages of zinc-aluminium alloys

- **Corrosion resistance:** The excellent corrosion resistance of zinc in many environments has led to its extensive use for corrosion protection. The Zinc-aluminium Foundry alloys, like unalloyed zinc, also possess excellent resistance to corrosion in a wide variety of environments.

- **Finishing:** Zinc alloy castings exhibit clean as-cast surfaces which can be anodized, painted, chromated, polished, brushed or plated. The type of finish selected will largely depend on service conditions, aesthetics and cost.

- **Painting:** The alloys lend themselves well to, pigmented organic coatings, including those that require baking. Surface pretreatments, such as chromating or phosphating, are necessary to ensure good adherence of paint or lacquer finishes. Coatings can be applied by brushing, spraying or dipping - the method used will depend largely on casting shape, complexity and quantity.

- **Machining:** The zinc-aluminium foundry alloys have excellent machinability and can tolerate wide variations in machining conditions. Tool life compares favorably with that experienced with copper and aluminium alloys and is significantly longer than with cast iron.

  In general, high-speed steel tools perform well. Best results are obtained with tools having large clearance angles and polished flutes and cutting surfaces. The use of water-soluble coolants is strongly recommended to prevent metal pickup on tools.

- **Strength and ductility:** Zinc alloys offer high ultimate tensile strength (up to 412 MPa) and superior elongation for strong designs, ability for bending, crimping and riveting operations.
• **Toughness:** Few materials provide the strength and toughness of zinc alloys. Impact resistance is significantly higher than cast aluminium alloys, plastics, and grey cast iron.

• **Anti-sparking:** Zinc alloys are nonsparking and suitable for hazardous location applications such as coal mines, tankers and refineries.

• **Process flexibility:** Any casting process can be used with zinc alloys to satisfy virtually any quantity and quality requirement. Precision, high-volume die casting is the most popular casting process. Zinc alloys can also be economically gravity cast for lower volumes using sand, permanent mold, graphite mold and plaster casting technology.

• **Precision tolerances:** Zinc alloys are castable to closer tolerances than other metals or molded plastics, therefore presenting the opportunity to reduce or eliminate machining. "Net Shape" or "Zero Machining" manufacturing is a major advantage of zinc casting.

• **Rigidity:** Zinc alloys have the rigidity of metals with modulus of elasticity characteristics equivalent to other die castable materials. Stiffness properties are, therefore, far superior to engineering plastics.

• **Bearing properties:** Bushing and wear inserts in component designs can often be eliminated because of zinc’s excellent bearing properties. For example, zinc alloys have outperformed bronze in heavy duty industrial applications.

• **Easy finishing:** Zinc castings are readily polished, plated, painted, chromated or anodized for decorative and/or functional service.

• **Thin wall castability:** High casting fluidity, regardless of casting process, allows for thinner wall sections to be cast in zinc compared to other metal.

• **Machinability:** Fast, trouble-free machining characteristics of zinc materials minimize tool wear and machining costs.
• **Low energy costs**: Because of their low melting temperature, zinc alloys require less energy to melt and cast versus other engineering alloys.

• **Clean and recyclable**: Zinc alloys are among the cleanest melting materials available. Zinc metal is non-toxic, and scrap items are reusable resources which are efficiently recycled.

Some of the general properties of zinc-aluminium alloy are presented in Table 3.2

### Table 3.2 General properties of zinc-aluminium alloy (ZA-27)

<table>
<thead>
<tr>
<th>Mechanical Properties</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength (MPa)</td>
<td>135-145</td>
</tr>
<tr>
<td>Young’s modulus ($10^3$XMPa)</td>
<td>77</td>
</tr>
<tr>
<td>Brinell hardness</td>
<td>105-115</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Physical Properties</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity (gm/cm$^3$)</td>
<td>5.0</td>
</tr>
<tr>
<td>Melting range ($^\circ$C)</td>
<td>450-950</td>
</tr>
</tbody>
</table>

### 3.2.2 Applications of zinc-aluminium alloys

The economic benefits and inherent properties of zinc-aluminium foundry alloys account for their use in a rapidly growing list of industrial applications, including

- Industrial fittings and hardware.
- Pressure tight housings.
- Sleeve bearings, thrust washers and wear plates.
- Electrical switchgear and hardware.
- Hose couplings and connectors.
- Fire fighting hardware.
- Pneumatic and hydraulic cylinder components.
- Industrial machine hardware.
- Electrical conduit fittings.
- Door hardware and lock components.
- Pulleys and sheaves.
- Non-sparking mine hardware.
- Decorative hardware.
- Electronic instrument chassis, hardware and covers.

The following are some of the advantages of using zinc-aluminium alloys in foundry.
- Low melting costs.
- Extended foundry environment.
- No fluxing or degassing.
- Excellent mould filling characteristics.
- Few casting rejects.
- Low melt losses.
- Excellent as-cast strength.

Advantages of using zinc-aluminium alloy in casting are
- High tensile strength and hardness.
- Excellent machinability.
- Superior pressure tightness.
- Good bearing and wear characteristics.
- Easily cast in thin sections.
- Wide choice of casting methods.

3.2.3 Pure zinc
Zinc is a silvery blue-grey metal with a relatively low melting point (425°C) and boiling point (907°C). When unalloyed, its strength and hardness is greater than that of tin or lead, but appreciably less than that of aluminium or
copper. The pure metal cannot be used in stressed applications due to low creepresistance. For these reasons most uses of zinc are after alloying with small amounts of other metals or as a protective coating for steel.

Except when very pure, zinc is brittle at ordinary temperatures, but malleable at about 100°C, and can then be readily rolled and hence unalloyed wrought zinc is used extensively for fully supported zinc roofing. However, small additions of copper and titanium appreciably improve the creep-resistance of rolled sheet, producing a material of growing industrial importance for roofing. With additions of around 22 percent aluminium, superplasticity can be developed. Nearly 15 percent of zinc is used in cast form. When it is alloyed with 4 percent or more aluminium, its strength and hardness are increased considerably. Such alloys have excellent castability and are cast mainly under pressure and also economy, but gravity and other casting processes are used particularly with newer alloys containing more aluminium.

A major application of zinc is as an alloying addition to copper, forming the range of brasses. By varying the proportion of zinc, copper alloys can be produced with a range of physical properties. One of the most useful characteristics of zinc is its resistance to atmospheric corrosion, and just over half of its use is for the protection of steelwork.

3.2.4 General properties of pure zinc

- Pure zinc is a bluish-white, shiny metal.
- Zinc is resistant to corrosion.
- Zinc has a relatively low melting point.
- Zinc has never been found naturally in its pure form.
- Zinc can be alloyed with a number of other metals.
• Zinc is brittle at room temperatures but is malleable and ductile when heated to 100°C.
• Zinc is a good electrical conductor and is fairly hard.

Some of the general properties of pure zinc are presented in Table 3.3

**Table 3.3 Properties of pure zinc**

<table>
<thead>
<tr>
<th>Mechanical Properties of Zinc</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength (MPa)</td>
<td>126</td>
</tr>
<tr>
<td>Young’s modulus (10^3 XMPa)</td>
<td>70</td>
</tr>
<tr>
<td>Brinell hardness</td>
<td>60</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Physical Properties of Zinc</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity (gm/cm^3)</td>
<td>7.14</td>
</tr>
<tr>
<td>Melting range(°C)</td>
<td>425-907</td>
</tr>
</tbody>
</table>

3.2.5 Aluminium

Pure aluminium is a silvery-white metal with many desirable characteristics. It is light, nontoxic, nonmagnetic and nonsparking. It is decorative. It is easily formed, machined, and cast. Aluminium alloys with small amounts of copper, magnesium, silicon, manganese, and other elements have very useful properties. Strength depends on purity. 99.996 per cent pure aluminium has a tensile strength of about 49MPa, rising to 700MPa following alloying and suitable heat treatment. Although not found free in nature, aluminium is an abundant element in the earth's crust. A key property is low density. Aluminium is only one-third the weight of steel.

Aluminium and most of its alloys are highly resistant to most forms of corrosion. The metal's natural coating of aluminium oxide provides a highly effective barrier to the ravages of air, temperature, moisture and chemical attack. Aluminium is a superb conductor of electricity.
Aluminium is non-toxic and impervious, qualities that have established its use in the food and packaging industries in the earliest times. Other valuable properties include high reflectivity, heat barrier properties and heat conduction. The metal is malleable and easily worked by the common manufacturing and shaping processes.

Some of the general properties of pure aluminum are presented in Table 3.4

<table>
<thead>
<tr>
<th>Mechanical properties aluminium</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength (MPa)</td>
<td>49</td>
</tr>
<tr>
<td>Young's modulus ($10^3$XMPa)</td>
<td>70</td>
</tr>
<tr>
<td>Brinell hardness</td>
<td>30</td>
</tr>
<tr>
<td>Physical Properties of aluminium</td>
<td></td>
</tr>
<tr>
<td>Specific gravity (gm/cm$^3$)</td>
<td>2.70</td>
</tr>
<tr>
<td>Melting range (°C)</td>
<td>580-960</td>
</tr>
</tbody>
</table>

These properties can be very significantly altered with the addition of small amounts of alloying materials. Aluminium reacts with oxygen to form a microscopic (0.0635μm) protective film of oxide, which prevents corrosion and in massive form it is non-flammable. But finely divided particles will burn and carbon monoxide or dioxide, aluminium oxide and water will be emitted. This is a useful property for making rocket fuel.

3.2.5.1 Advantages of aluminium

- **Lightweight:** The specific gravity of aluminium is 2.7, about one-third that of iron (7.9) and copper (8.9). This feature is particularly important in transportation industries: for example, aircraft, automobiles, trains and ships.
• **Excellent corrosion resistant:** When aluminium is exposed to air, a thin oxidised film forms on the surface protecting the metal from corrosion. Anodising can make corrosion resistance even more effective. This feature is utilized in building constructions and household utensils.

• **Easy to work:** Aluminium can be easily fabricated into various forms such as foil, sheets, rods, tubes, and wires. It also displays excellent machinability and plasticity in bending, cutting, and drawing. Aluminium is considered to be the best material for complex-sectioned hollow extrusion.

• **Non-toxic:** Aluminium itself is non-toxic and odorless. Its surface is smooth, easily washable, and hygienic because no germs can grow on it. Due to these features, it is widely used in beverage cans, food packaging, cooking utensils, and in the fishery and dairy industries.

• **Strong at low temperatures:** Although steel becomes brittle at low temperatures, aluminium increases in tensile strength and retains excellent quality. Aluminium can also be used in extreme atmospheric conditions.

• **Strong:** The tensile strength of pure aluminium is not high, but depending upon the alloy or temper, strength of up to 130 MPa can be reached. One can choose the alloy with the most suitable strength characteristics according to required application. Some alloys are stronger than ordinary steel or even equal to special steel in tensile strength.

• **Good electric conductor:** The electrical conductivity of aluminium is approximately 60% that of copper. However, aluminium weighs about one-third as much as copper of the same mass. Aluminium is a very economical material as an electric conductor and is widely utilized in power-transmission cables, bases of electric bulbs, and in other electric fields.

• **Good heat conductor:** Aluminium is about three times as thermal-conductive as steel. It is used in utensils which are used for cooking, air-
conditioners, industrial heat exchangers, and automobile engine parts. It is also used in solar collectors.

3.3 Origin of garnet crystals

Calc-alkaline dacites and rhyolites from the Setouchi volcanic belt contain garnet crystals that are classified spectrographically and chemically into two types:

- Type-M
- Type-I

Type-M garnets are characterized by acicular sillimanite inclusions or dissolved textures, and are sometimes accompanied by xenolith fragments. They have a high manganese oxide/calcium oxide ratio and extensive compositional zoning with an increase in both magnesium and (iron oxide + magnesium oxide)/(calcium oxide + manganese oxide) towards the margin. These features are identical to those of garnets observed in meta-sediment xenoliths within the host rocks, suggesting a xenocrystic origin for the type-M garnets.

In contrast, type-I garnets, accounting for 75% of garnets examined, are rich in calcium oxide and show oscillatory zoning characterized by an antipathetic variation between iron oxide and magnesium oxide. Transmission Electron Microscope (TEM) analysis revealed the presence of minute glass inclusions in the type-I garnets, which is conclusive evidence that the garnet grew in the presence of a melt. The type-I garnets show no evidence to support an origin as a reaction product grown through a melting reaction in wall rocks or source materials. Therefore, type-I garnets are concluded to be magmatic in origin. A systematic relationship between the compositional oscillatory zoning and the distribution of minute glass inclusions is best explained by the interaction between garnet growth and diffusion in the melt.
Garnets are isostructural, meaning that they share the same crystal structure. This leads to similar crystal shapes and properties. Garnets belong to the isometric crystal class, which produces very symmetrical, cube-based crystals. The most common crystal shape for garnets however is the rhombic dodecahedron, a twelve sided crystal with diamond-shaped (rhombic) faces.

The general formula for most of the garnets is $A_3B_2(SiO_4)_3 [Fe_3 Al_2 (SiO_4)_3]$. A represents divalent metal such as calcium, iron, magnesium and/or manganese. B represents trivalent metals such as aluminium, chromium, iron and/or manganese. The main differences in physical properties among the members of the garnet group are slight variations in colour, density and index of refraction.

3.3.1 General characteristics of garnet

The following are some of the general characteristics of garnet

- Crystal System: Isotropic.
- Hardness: 6.5-7.5
- Specific Gravity: 3.5-4.2 gm/cm$^3$
- Index of Refraction: 1.73-1.89.
- Melting point of the garnet: 1380$^0$C.

3.4 Properties of garnet groups

Properties of most common members of garnet are shown in table 3.5
Table 3.5 Properties of garnet

<table>
<thead>
<tr>
<th>Mineral Name</th>
<th>Chemical formula</th>
<th>Specific gravity (gm/cm³)</th>
<th>Refractivity index</th>
<th>Typical colour</th>
<th>Environment of formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almandine</td>
<td>Fe₃Al₂(SiO₄)₃</td>
<td>4.3</td>
<td>1.83</td>
<td>Reddish brown to brown</td>
<td>M-schists &amp; gneisses; I-pegmatites (rarely)</td>
</tr>
<tr>
<td>Andradite</td>
<td>Ca₃Fe₂(SiO₄)₃</td>
<td>3.8</td>
<td>1.89</td>
<td>Brown, black or green</td>
<td>M-serpentinites &amp; skarns; I-volcanic</td>
</tr>
<tr>
<td>Grossular</td>
<td>Ca₃Al₂(SiO₄)₃</td>
<td>3.5</td>
<td>1.75</td>
<td>Colourless, orange or green</td>
<td>M-contact marbles &amp; serpentinites</td>
</tr>
<tr>
<td>Pyrope</td>
<td>Mg₃Al₂(SiO₄)₃</td>
<td>3.6</td>
<td>1.73</td>
<td>Dark red to ruby red</td>
<td>M-serpentinites &amp; gneisses; I-dunites &amp; kimberlites</td>
</tr>
<tr>
<td>Spessartine</td>
<td>Mn₃Al₂(SiO₄)₃</td>
<td>4.2</td>
<td>1.80</td>
<td>Orange, pink or brown</td>
<td>M-gneisses &amp; marbles; I-pegmatites &amp; granites</td>
</tr>
<tr>
<td>Uvarovite</td>
<td>Ca₃Cr₂(SiO₄)₃</td>
<td>3.8</td>
<td>1.86</td>
<td>Green</td>
<td>M-serpentinites</td>
</tr>
</tbody>
</table>

3.4.1 The Mineral Almandine

The chemical formula of almandine is Fe₃Al₂(SiO₄)₃ (Iron aluminium silicate) under the class of silicates, which belongs to garnets group and used as abrasive. Fig. 3.1 shows the general structure of mineral almandine.

Fig. 3.1 Mineral Almandine
Almandine is the most common of the garnets and is usually the garnet found in garnet schists (a type of metamorphic rock composed mostly of mica). Precious transparent crystals are frequently used as gemstones along with its close cousin, Pyrope. Pure almandine and pure pyrope are rare in nature and most specimens are a percentage of the two. The change in specific gravity of almandine (4.3) to pyrope (3.6) is the only good test to determine a specimen’s likely identity.

Physical characteristics:

- **Colour:** Typically red to brown, sometimes with a tinge of purple and sometimes a deep enough red to appear black.
- **Crystal system:** Isometric.
- **Crystal habits:** Typical rhombic dodecahedron. Also seen is 24 sided trapezohedron. Combinations of these forms are common and sometimes the rare faces of the hexoctahedron, a 48 sided crystal habit that rarely is seen by it, can also combine with these other forms making very attractive, complex and multifaceted crystals. Massive occurrences are also common.
- **Fracture:** Conchoidal.
- **Hardness:** 6.5 - 7.5
- **Specific gravity:** 4.3 gm/cm³.
- **Notable occurrences:** Wrangel Alaska; Germany; Norway and India.
- **Best field indicators:** Crystal habit, colour, density and hardness.

### 3.4.2 The Mineral Andradite

The chemical formula of andradite is Ca₃Fe₂(SiO₄)₃ (Calcium iron silicate) under the class of silicates, which belongs to garnets group and used as abrasive. Fig. 3.2 shows the general structure of mineral andradite.
Andradite is the calcium iron garnet and forms in contact or regional metamorphic environments as does grossular, the calcium aluminium garnet. It is believed that these garnets form the metamorphism of impure siliceous limestone.

**Physical characteristics:**
- **Colour:** Typically greenish gray to green but also black, yellow and sometimes colourless.
- **Crystal system:** Isometric.
- **Crystal habits:** Typical rhombic dodecahedron. Also seen is the 24 sided trapezohedron. Combinations of these forms are common and sometimes the rare faces of the hexoctahedron, a 48 sided crystal habit that rarely is seen by it, can also combine with these other forms making very attractive, complex and multifaceted crystals. Massive occurrences are also common. Commonly forms crust that shows many rhombic faces
- **Fracture:** Conchoidal.
- **Hardness:** 6.5 - 7.5
- **Specific gravity:** 3.8 gm/cm$^3$. 
- **Notable occurrences:** Arizona; Ural Mountains in Russia; Italy and California.
- **Best field indicators:** Crystal habit, colour, index of refraction and hardness.

### 3.4.3 The Mineral Grossular

The chemical formula of grossular is $\text{Ca}_3\text{Al}_2(\text{SiO}_4)_3$ (Calcium aluminium silicate) under the class of silicates, which belongs to garnets group and used as abrasive, mineral specimens and gemstone. Fig. 3.3 shows the general structure of mineral grossular.

![Fig. 3.3 Mineral Grossular](image)

Grossular is the calcium aluminium garnet and forms in contact or regional metamorphic environments as does andradite the calcium iron garnet. It is believed that these garnets from the metamorphism of impure siliceous limestone. Grossular has many colour possibilities and is probably the most colourful of the garnets.
Physical characteristics:

- **Colour:** Colourless, yellow, orange, green, red, grey and black.
- **Crystal system:** Isometric.
- **Crystal habits:** Typical rhombic dodecahedron. Also seen is the 24 sided trapezohedron. Combinations of these forms are common and sometimes the rare faces of the hexoctahedron, a 48 sided crystal habit that rarely is seen by itself, can also combine with these other forms making very attractive, complex and multifaceted crystals. Massive and granular occurrences are also seen. Commonly forms crusts that show many rhombic faces
- **Fracture:** Conchoidal.
- **Hardness:** 6.5–7.0
- **Specific gravity:** 3.5 gm/cm³.
- **Notable occurrences:** Canada; Mexico; Kenya; Italy and Sri Lanka.
- **Best field indicators** are crystal habit, colour, environment and hardness.

### 3.4.4 The Mineral Pyrope

The chemical formula of pyrope is Mg₃Al₂(SiO₄)₃ (Magnesium aluminium silicate) under the class of silicates, which belongs to garnets group and used as abrasive. Fig. 3.4 shows the general structure of mineral pyrope.

![Fig. 3.4 Mineral Pyrope](image_url)
Although less common than most other garnets, pyrope is a common gemstone. Most pyrope comes from ultramafic igneous rocks that contain olivine and/or diamond. Metamorphic pyrope comes from the metamorphism of the igneous rocks previously mentioned or from magnesium rich rocks subjected to high grade metamorphism.

**Physical characteristics:**

- **Colour:** Red to reddish purple and sometimes a deep enough red to appear black.
- **Crystal System:** Isometric.
- **Crystal Habits:** Typical rhombic dodecahedron. Also seen is the 24 sided trapezohedron. Combinations of these forms are common and sometimes the rare faces of the hexoctahedron, a 48 sided crystal habit that rarely is seen by it, can also combine with these other forms making very attractive, complex and multifaceted crystals. Massive and granular occurrences are also common.
- **Fracture:** Conchoidal.
- **Hardness:** 7.0 -7.5
- **Specific Gravity:** 3.6 gm/cm³.
- **Notable Occurrences:** Europe; Arizona and New Mexico, USA; South Africa and several Australian sites.
- **Best Field Indicators:** Crystal habit, colour, hardness and environment.

### 3.4.5 The Mineral Spessartine

The chemical formula of spessartine is $\text{Mn}_3\text{Al}_2(\text{SiO}_4)_3$ (Manganese aluminium silicate) under the class of silicates, which belongs to garnets group and used as abrasive, mineral specimens and gemstone. Fig. 3.5 shows the general structure of mineral spessartine.
Spessartine is formed in manganese rich metamorphic environments and in some granitic pegmatites. Spessartine is somewhat rare but occasionally will accompany other minerals and make a nice accessory mineral to an outstanding mineral specimen.

**Physical characteristics:**
- **Colour:** Orange, reddish brown, brown, pink and yellow.
- **Crystal System:** Isometric.
- **Crystal Habits:** Typical rhombic dodecahedron. But more commonly is found as the 24 sided trapezohedron. Combinations of these forms are common and sometimes the rare faces of the hexoctahedron, a 48 sided crystal habit that rarely is seen by it, can also combine with these other forms making very attractive, complex and multifaceted crystals. Massive and granular occurrences are also seen.
- **Fracture:** Conchoidal.
- **Hardness:** 7.0
- **Specific Gravity:** 4.19 gm/cm$^3$.
- **Notable Occurrences:** Pakistan; Madagascar; Brazil and Sri Lanka.
• **Best Field Indicators:** Crystal habit, colour, and hardness

### 3.4.6 The Mineral Uvarovite

The chemical formula of uvarovite is $\text{Ca}_3\text{Cr}_2(\text{SiO}_4)_3$ (Calcium chromium silicate) under the class of silicates, which belongs to garnets group and used as mineral specimens. Fig 3.6 shows the general structure of mineral uvarovite.

![Fig. 3.6 Mineral Uvarovite](image)

Uvarovite, like other garnets, forms rounded crystals with 12 rhombic or 24 trapezoidal faces or combinations of these and some other forms. This crystal habit is classsilicon carbide for the garnet minerals. Uvarovite is the only consistently green garnet and has a beautiful emerald-green colour. As with the other calcium garnets (andradite and grossular), uvarovite is formed from the metamorphism of impure siliceous limestone and some other rocks that contain chromium. Mineral specimens of uvarovite are much sought after by collectors for outstanding brilliance and colour.
Physical characteristics:

- **Colour:** Bright green.
- **Crystal System:** Isometric.
- **Crystal Habits:** Typical rhombic dodecahedron. But more commonly is found as the 24 sided trapezohedron. Combinations of these forms are common. Massive and granular occurrences are also seen.
- **Fracture:** Conchoidal.
- **Hardness:** 6.5 – 7.0
- **Specific Gravity:** 3.8 gm/cm³.
- **Notable Occurrences:** Finland; Sarany, Ural Mountains Region, Russia; California and South Africa.
- **Best Field Indicators:** Crystal habit, colour, locality and hardness.