CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter begins with an introduction, characteristics, and research status of industrial solid waste and conventional mold materials, with an emphasis on its characteristics and utilization have been reviewed.

Industrial solid waste and conventional mold material emphasis are:

- Blast furnace slag (BS)
- Ferrochrome slag (FS)
- Red mud (RM)
- Olivine sand (OL)
- Silica sand (SS)

2.2 Blast furnace slag

In iron and steel making, the maximum recovery of metal from metal-ore is ensured by the use of various fluxes and the entire unwanted material is removed as "**slag".** The huge flow of slag generated in the iron and steel making is shown in figure 2.1. This slag is made up of fused oxides of iron, aluminium, manganese, magnesium, calcium, phosphorous, and silicates of calcium in addition to ferrites. The grade of the iron ore and the process conditions affect the slag's chemistry. BS is classified based on cooling methods such as air-cooled, granulated, expanded, and pelletized[28–30].

2.2.1 Characteristics of blast furnace slag

The grade of the iron ore, the method of processing, the operating temperature, and the level of basicity used in the manufacture of iron all affect the chemical composition of the slag. SiO_2, MgO, and Al_2O_3/Fe_2O_3 are the principal phases found in slag and are given in table 2.1[31–36].

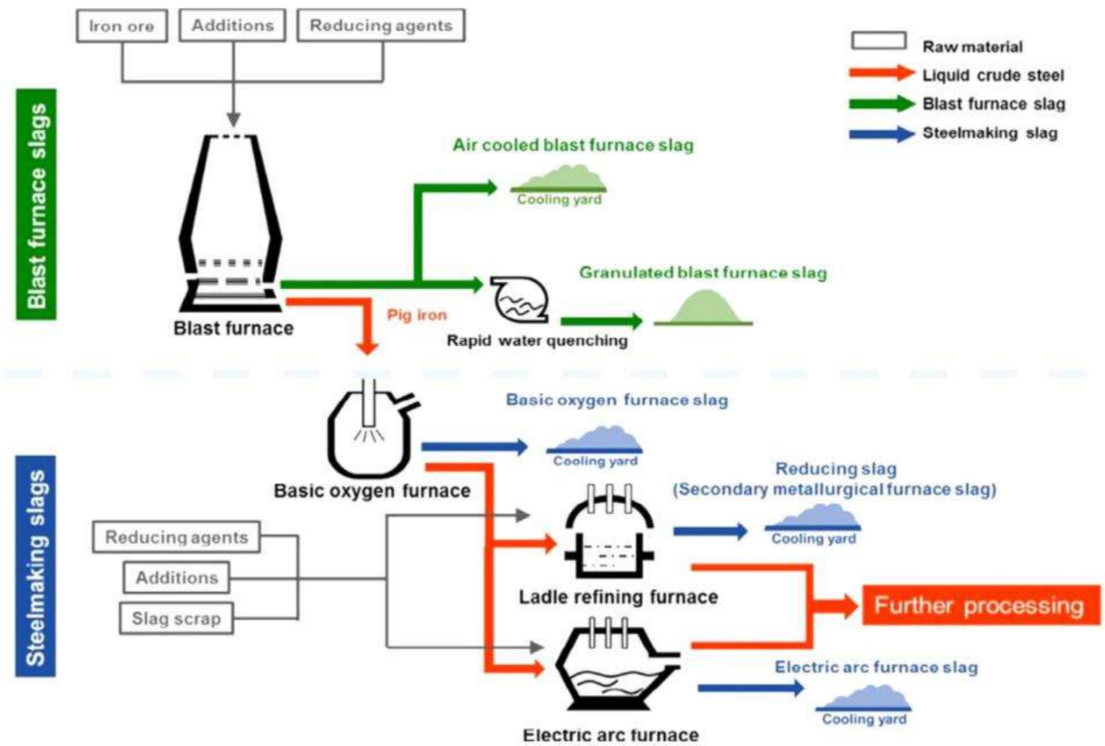

Figure 2.1: Process flow of blast furnace slag[37]

Table 2.1: Composition of Blast furnace slag

Authors / Composition	CaO	SiO_2	Al_2O_3	MgO	Fe_2O_3
Yingbin Wang[38]	38.6%	36.9%	12.3%	7.5	0.3
Ziuhong Ma[39]	37.69	34.26	18.02	8.05	0.25
JunjunWu[40]	32-41.5	33-47.5	5.5-19.3	2.5-13.8	-

The first rigorous definition of acid and basic behaviour was given by Arrhenius in 1884. In his definition, the addition of acid and base compounds in water increases the concentration of H+ and OH- in water or solution respectively. In slag, acid oxides, and basic oxides behaves as network formers and network breaker respectively. Also, the covalent bonding dominates over ionic bonding in acid oxide and ionic bonding dominates over covalent bonding in basic oxide. The basicity of oxide is defined as the ratio of basic oxide to acid oxide, depending on the numerical value of these ratios, if the ratio is > 1 term as basic oxide, and if the ratio is < 1 term as acid oxide [41,42].

2.2.2 Research status of comprehensive utilization of blast furnace slag

The focus of various researchers is to utilize blast furnace slag based on their mineralogical composition. The slag as a substitute for cement reduces pollution, but high energy consumption during cement production. In 1800, Germany produced blast furnace slag cement by mixing lime and slag and since the 1860s the production of slag cement commercialized [43]. "**Slag cement" is** termed due to the use of slag in the cement industries.

Tsai et al.[44] used ground-granulated basic oxygen furnace slag (GGBOS) and ground-granulated blast furnace slag (GGBS) to prepare cementitious materials. It was found that the compressive strength increases up to 80% - 90 % with a range from GGBOS: GGBS (by weight) 3:4 to 6:5 after 91 days. The slag increases the alkali environment required for a satisfactory reaction. M.L. Berndt[45] replaced 50% of cement with blast furnace slag resulting in enhanced mechanical and durability properties. Initially, the compressive strength was lower with slag in concrete due to the low hydration process. The rate of hydration was increased by reactive slag which increased the density and agglomerates bonding, results in high compressive strength[46]. The degree of reaction of the slag blended with calcium sulfoaluminate (CSA) cement was increased by carbonation after the aging of 28 days. As the carbonation commenced, it results in the enhancement of the concrete strength[47]. The variation in the percentage of blast furnace slag content in cement estimated that 50% slag is recommended based on strength performance, carbon footprints, and cost efficiency[48]. The replacement of blast furnace slag (GGBFS) with Portland cement shows the corrosion resistance behaviour of concrete in coastal areas and marine structures as the decrease in the permeability of chloride ions. Upto 60% GGBFS shows the significantly reduction in corrosion rate[49]. The durability of Portland cement enhanced with the accurate % of blast furnace slag and curing time with the effectiveness in improving resistance to chlorides, sulphate, and alkali–silica reactions [50].

2.3 Ferrochrome slag

Ferrochrome slag is a by-product of ferrochromium alloy produced during the production of ferrochromium alloy steel in a submerged electric arc furnace. Ferrochrome is an alloy of iron and chromium, containing 45% - 80% Cr and various amounts of Fe, C, and other elements. The Pyrometallurgically route is used for the production of ferrochromium from chromite ore by carbothermic reduction ($FeO \cdot Cr_2O_3$). During the process, chromium and iron react with carbon and are reduced to form metal products. Based on chromium content, the alloy was classified into four groups (i) Cr>60 and is called high carbon FeCr (ii) 50-60% Cr and 6-9% C as charge FeCr (iii) 50-70% Cr and 1-4% C as medium carbon FeCr (iv) 50-70% Cr and 0.015-1.0% C as low carbon FeCr. The waste of FeCr production is termed ferrochrome slag. The slag is mainly consisting of SiO_2, Al_2O_3, and MgO in different phases such as spinel, $MgO \cdot Al_2O_3$, and forsterite, $MgO \cdot SiO_2$, but also smaller amounts of CaO, chromium, and iron oxides and metal fragments. The ratio of slag/metal depends on the grade of chromite which varies in the range of 1.0-1.8[51–55].

The mineralogy of the ferrochrome slag mainly depends on the chemical composition and cooling characteristics of the quaternary system CaO-Al_2O_3-MgO-SiO_2. The chemical composition of slag depends on the grade of ore, flux, oxygen partial pressure, and operating temperature. The major phase of slag is Spinel, Forsterite (M_2S), Enstatite (MS), and Anorthite (CAS_2) and minor Phases are Spine, Chromium carbide (Cr_7C_3) [56–58].

2.3.1 Characterization of ferrochrome slag

The chemical composition of ferrochrome slag depends on the type of ore, fluxing materials, residence time in high temperature, oxygen partial pressure, and cooling rate. The major constituents of ferrochrome slag are SiO_2, Al_2O_3, Fe_2O_3, MgO, and Cr_2O_3 are listed in table 2.2.

Table 2.2: Composition of ferrochrome slag[59]

SiO_2	Al_2O_3	Fe_2O_3	MgO	MgO	CaO	Na_2O	Cr_2O_3
13-39%	16-43%	3-11%	0-0.7%	10-38.5%	1-6%	0.02-0.2%	6-18%

2.3.2 Research status of comprehensive utilization of ferrochrome slag

M.K Dash et al. showed that ferrochrome slag can be used as concrete materials. Water-cooled ferrochrome slag replaces upto 30% of sand in concrete. A comparison of properties such as tensile strength, compressive strength, and flexural strength of concrete made of slag concrete with natural aggregates. The results showed that it was beneficial based on environmental, economic, and concrete properties to use 30% slag concrete[60]. With a combination of fly ash, ferrochromium slag can be used as construction materials. P. K Acharya et al. and Gencel et al. studied the combined effect of ferrochrome slag and fly ash. Results of the investigation revealed the improvement in strength and durability properties of concrete with the inclusion of fly ash and ferrochrome slag, use of ferrochrome slag increases the strength of concrete and wear resistance whereas fly ash lowers the wear resistance, tensile strength, and compressive strength[61]. In the comparison of the slag and crushed limestone aggregates suitable for high concrete brands, the results showed that slag is suitable whereas the limestone is not suitable to provide desired properties of concrete pavement such as compressive strength, wear resistance, etc[62]. K.A Jabri et al.[63] replaced sand in the cement mortar with ferrochrome slag upto 20%. In their study, they found that after 28 days of curing compressive and flexural strength shows significant enhancement in the ratio of about 33% and 39% at 20% slag. Due to the presence of amorphous silica, release a sufficient amount of calcium silicate hydrate (CSH) as the pozzolanic reaction began, which improves the bonding between slag and cement and also roughness as well as irregularities of slag grain also contributes to the enhancement of desired properties. Ferrochrome slag was utilized with the nano metakaolin (NMK) in the cement mortar. K.A Jabri et al.[64] studied the combined effect of nano metakaolin and ferrochrome slag on mechanical strength, drying shrinkage, capillary water absorption, and thermal conductivity of cement mortar. Sand replacement by 50% ferrochrome slag shows enhancement in compressive and flexural strength, dry shrinkage resistance, and thermal conductivity whereas nano metakaolin addition with slag improved mechanical and thermo-physical properties of slag. The bonding between slag and cement was enhanced by the NMK, which influence the interfacial transition zone.

2.4 Red Mud

Red mud is the solid waste generated during the production of alumina from bauxite ore through the Bayer process as shown in figure 2.2 and equation (2.1 - 2.4), Karl josephs Bayer's in 1888 patent the Bayer's process. Aluminium metal produces electrochemically from alumina by the Hall-Heroult process. Bauxite is the main source of aluminium production (approximately 98%). Bauxite is naturally occurring as the in-situ weathering of the rock, the main constituent is aluminium oxide and the rest of all are the oxides of iron, silica, titania, and some of the trace elements[65–68]. The aluminum is produced from bauxite having aluminium-bearing minerals (i) Gibbsite ($Al(OH)_3$) (ii) Boehmite ($AlO(OH)$) (iii) Diaspore ($AlO(OH)$). The Bayer's process, use concentrated sodium hydroxide solution for the digestion of crushed bauxite at 270℃. The solution dissolved the majority of aluminum content present in the ore and leave insoluble resides such as red mud, the process is followed by the reaction listed below. The main geographic sources of bauxite are mainly such as Africa (33%), the west indies, the Caribbean and South America (22%), Australia, and Asia (15%) as shown in figure 2.3 [69–72].

Extraction: $\mathbf{Al(OH)_{(s)} + Na(OH)_{aqs} \rightarrow Na^{+}Al(OH)^{-}_{4(aqs)}}$ (2.1)

$\mathbf{AlO(OH)_{(s)} + NaOH_{(aqs)} + H_2O \rightarrow Na^{+}Al(OH)^{-}_{4(aqs)}}$ (2.2)

Precipitation: $\mathbf{Na^{+}Al(OH)^{-}_{4(aqs)} \rightarrow Al(OH)_{3(s)} + NaOH_{(aqs)}}$ (2.3)

Calcination: $\mathbf{2Al(OH) \rightarrow Al_2O_3 + 3H_2O}$ (2.4)

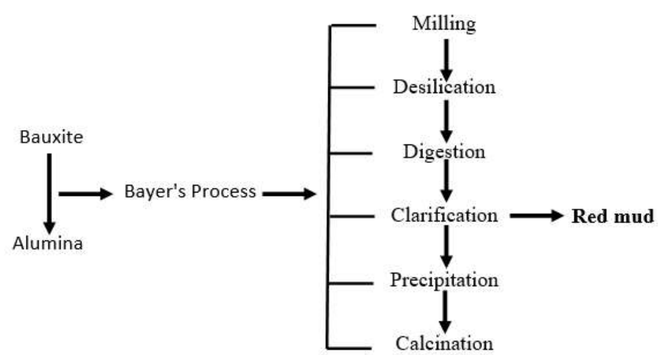

Figure 2.2: Process diagram of Bayer's process[72,73]

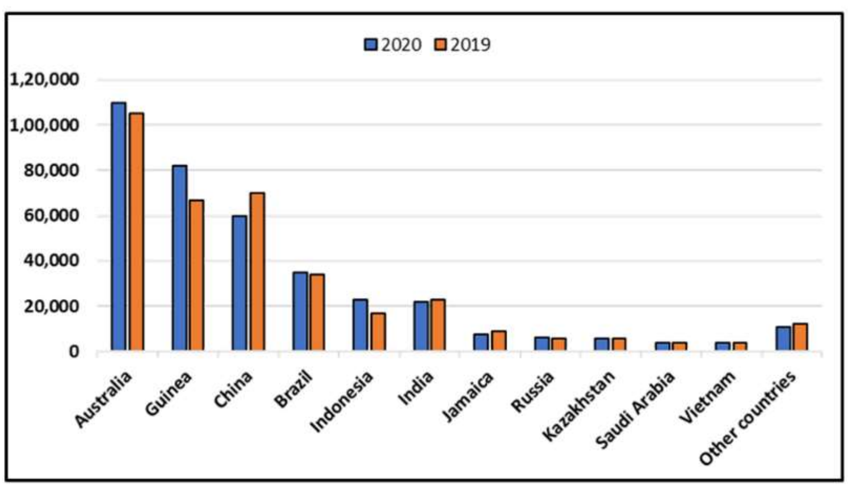

Figure 2.3: Major country bauxite production(2019-2020)(in 1000 metric tons)[74]

2.4.1 Characterization of red mud

The chemical composition of red mud depends on the grade of bauxite ore and the production process of aluminum. The major constituents of red mud are Fe_2O_3, Al_2O_3, SiO_2, CaO, Na_2O, TiO, K_2O, and MgO listed in table 2.3.

Table 2.3: Chemical composition

Authors / Composition	Fe_2O_3	Al_2O_3	SiO_2	CaO	Na_2O	TiO	K_2O	MgO	SO_3
NALCO[75]	22.79	21.24	23.90	9.90	5.83	5.50	2.49	8	-
Hindalco[76]	34.3	29.5	8.6	5.2	5.45	15.3	-	-	-
Brazil[77]	35.5	12.6	11.7	14.8	4.6	15.2	-	1.1	-
China[78]	29.11	22.32	27.40	1.57	6.70	-	0.17	0.17	0.23
Australia[79]	60	15	5	-	16	5	-	-	-
Spain[80]	37	12	9	6	5	20	-	-	-

2.4.2 Research status of comprehensive utilization of red mud

Singh et al. [81,82] study the strength of cement prepared with a combination of red mud, lime, bauxite, and gypsum with ordinary Portland cement and observed that the cement prepared with the combination of red mud shows superior strength as compared with Portland cement and also study the effect of firing time, composition and firing temperature on cement properties. The formation of C_4AF (aluminoferrite), C_3A(aluminates), and C_4A_3S (calcium sulfoaluminate) phases is responsible for the strength of red mud, lime, gypsum, and bauxite cement. Xianhai Li et al.[83] modified the aggregates with the change of surface properties of aggregates by using red mud(RM) with a specific solid-liquid ratio and observed that the presence of RM in concrete increased the compressive and flexural strength by 10% and 20% respectively with concrete prepared with limestone. Mansour et al. [84] study the effect of red mud, granite, and marble waste powder on the self-compacting strength of concrete and observed that the use of red mud upto (2% - 5 %) enhanced the mechanical properties but beyond these limits might decrease the overall performance this is due to larger surface area of red mud, which will reduce the free water content in the concrete. Krivenko et al. [85] used a combination of red mud, blast furnace slag, and aluminosilicate for the alkali-activated cement. The alkali-activated allows an increase in the percentage of red mud in cement and concrete with a decrease in the physio-mechanical performance of cement and concrete [86–90].

Red mud is used as a reinforced or filler material to enhance the properties of a composite. The performance of red mud-based composite attracts researchers nowadays. Many authors study the behaviour of red mud-based composites such as alloys, hybrid composites, functional composites, polymers, plastics, etc. have been widely studied. Vigneshwaran et al. [91] used red mud and sisal fiber as filler material and polyester matrix for the fabrication of a hybrid composite. They investigated the effect of red mud on tensile strength, impact strength, water absorption, void, and density of composite, which find that the strength enhanced with the addition of 10% - 20 % red mud as a result of good bonding with matrix and fiber. Prasad et al. [92] used fly ash and red mud as reinforced in the A356 alloy via friction stir process, stir casting process to reinforce red mud in 6061 matrix[93], ANN model used to investigate the wear properties of red mud reinforced aluminum matrix and observed that as the strength and wear properties increases as the volume fraction of red mud increases, wear rate decreased upto 10 % of red mud beyond theses increased the wear rate[94]. Guru et al. [95] used red mud as filler material for the fabrication of neutron shielding polyester composite.

2.5 Olivine sand

Olivine is a silicate mineral of magnesium and iron (Mg, Fe) $SiO_{2\ is}$ considered a natural mineral that mainly occurs in the region of mafic to ultramafic ingenious rock. The naturally occurring olivine has a composition in the range of pure forsterite (Mg_2SiO_4) to pure fayalite (Fe_2SiO_4), the variation in the ratio of magnesium to iron comes within this range. The percentage dominates of magnesium silicate in a mixture termed olivine. The appearance of olivine such as colors ranges from yellowish green, olivine green, greenish black, and reddish brown. Crystals of olivine possess orthorhombic symmetry and a structure made up of a variety of unique (SiO_4) tetrahedral units with separate oxygen atoms acting as connecting atoms (unlike the pyroxenes, amphiboles, or feldspars which form linked SiO_4 polymers). The oxygen atoms that make up the individual tetrahedral units of the olivine structure are arranged in planes that are parallel to the x-axis; they are roughly aligned hexagonally in each plane but are not touching one another[96–98]. Refractory bricks and ramming mixes were first made from olivine at the foundries [96]. Dunnites, an igneous rock, is where most olivine is found. Alluvial deposits, or natural sand deposits, are considered minor deposits. In 1927–1928, Norwegian steel foundries made their first attempts to use crushed olivine as a molding aggregate. Although it cost more than silica, it gave steel castings an adequate surface polish, especially for high chromium-nickel steels. Due to the long-term effects of breathing silica dust, silicosis, olivine's use as a molding aggregate increased in the early 1940s. Rats and rabbits were used in experiments with silica and olivine dust in the 1940s. The tests revealed that olivine dust appeared to be less hazardous than silica, according to the data. As opposed to utilizing pure silica sand, olivine contains MgO that is chemically bound to the silicon dioxide, which was thought to minimize the risk of silicosis [97].

2.5.1 Characterization of Olivine sand

The chemical composition of olivine varies with several reactions that occur during the metamorphism of carbonate rocks are listed in table 2.4. The most available natural form of the olivine group is forsterite-fayalite. The iso-chemically reaction leads to the formation of forsterite and calcite from dolomite as per equation 2.5 [99–101].

Dolomite (Ca Mg $(CO_3)_2$) + Silica (SiO_2) = Forsterite (Mg_2SiO_4) + Calcite + CO_2 (2.5)

Table 2.4: Chemical composition of several olivine sand

Authors / Composition	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**MgO**	**CaO**	**NiO**	**Cr_2O_3**
Emmanuel.et al.[99]	40.02	5.98	8.04	44.01	0.20	-	-
Gule et al.[102]	40.91	0.234	9.678	48.73	0.29	-	-
Christodoulou et al.[103]	40.97	2.84	-	42.19	7.21	-	-
Pan et al.[104]	44.77	1.00	9.57	42.95	1.09	0.38	-
Kliev et al.[105]	42.0	0.45	7.20	49.4	0.09	0.31	0.30
Knutssona et al.[106]	41.0	0.30	9.50	48.9	0.13	0.30	0.57
Acar[100]	38.24	0.72	7.32	50.03	-	-	1.59
Zhang et al.[107]	35.88	0.65	9.28	52.94	-	0.38	0.39
Marinkovic et al.[108]	41.7	0.46	7.4	49.6	-	0.32	0.31
Westgate et al.[96]	40.2	1.2	8.5	48.7	-	-	-
Vilches et al.[109]	41.7	0.46	7.4	49.6	-	0.32	0.31

2.5.2 Research status of comprehensive utilization of olivine sand

The thermal stability of olivine sand restricts the utilization of olivine sand in foundry industries where high thermal stability is required. Olivine has been utilized in foundry applications where low or moderate thermal stability is required. One of the important factors that olivine sand utilization, minimize the amount of silica dust which is responsible for silicosis disease as well as also available as low-cost-silica-free sand for foundry application. Generally, for the foundry application olivine sand consist of magnesium silicate (67%-74%) and iron silicate (11%-20%) and the rest are minor silicate and SiO_2 based on literature[98].

2.6 Silica sand

Silica sand or silica also known as quartz, is one ubiquitous material on the earth's surface. Rock weathering is the continuous part of the rock cycle, which creates rock formation and erosion. The erosion of rock leads to the generation of sand which is an important constituent of igneous, sedimentary, or metamorphic depends on the traveling of erosive rock with the transportation of rain water[110]. Quartz, quartz crystal, sand, silica sand, molding sand, etc are commonly called "silica minerals" because having the major phase of SiO_2 with the rest of the trace elements. Indian statics of silica sand as per the NMI database 2015, estimated at 3907.95 million tons of which 17% are reserved and 83% under the resources category. The resource category is based on the application of silica sand as shown in figure 2.4 [111].

In a geologic sense, sand refers to particles of earth materials in the size range between 1/16 and 2 mm. The particles, or grains, may have similar properties or may differ greatly in shape, colour, and hardness depending on the combination of chemical constituents of which they are composed. As resource materials, silica sands have a very high content of clear grains of the mineral quartz, and one important use of silica sand is as the main constituent used to make glass.

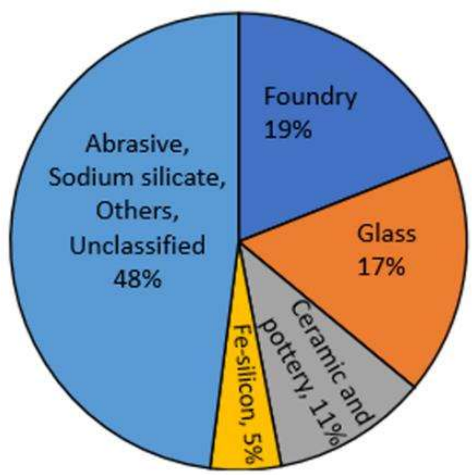

Figure 2.4: Silica sand resources as per grade[111]

2.6.1 Silica sand phase

Structurally silica is a three-dimensional SiO_4 tetrahedra structure. This structure consists of Si in the center and O at every four corners with an angle between Si-O-Si of 109°. The stable phase of silica at 1 atm is a function of temperature, the stability of phases is based on the free energy of corresponding phases. The polymorphic structure is quartz, cristobalite, and tridymite as shown in figure 2.5 [112–115].

Liquid silica
↕ 1710°C
Cristobalite
↕ 1470°C
Tridymite
↕ 876°C
α-quartz
↕ 573°C
β-quartz

Figure 2.5: Phases of silica sand[112,114]

2.6.2 Characterization of silica sand

Physical-chemical characterization of silica sand revealed that the major minerals are SiO_2 about 98 %, minor minerals are Al_2O_3(<1.18%), and Fe_2O_3, Na_2O, K_2O, and TiO_2(<0.6%) listed in table 2.5 [116]. The physical, chemical, and mechanical properties of silica sand depend on the constituents present in it[117].

2.6.3 Research status of comprehensive utilization of silica sand

There are several industrial and specialized horticulture uses for silica sands, which are vital raw materials for the production of glass. Historically, foundries were a significant market for silica sand. Indian foundry practices, which are the oldest in the world as well as one of the oldest manufacturing processes. Foundry industries used sand mold for casting ferrous and non-ferrous alloys, which were made of natural silica sand across the countries because of its availability, relatively inexpensive, wide grain size range, flexibility, high melting point etc[118–121]. Mold aims to provide a flexible cavity of the desired shape, where liquid metal or alloy solidified in the desired shape. The sand casting process involves (i) mold preparation (ii) pouring of liquid alloy into the mold (iii) solidification of alloy (iv) extraction of cast alloy after mold breaking[122].

Table 2.5: Chemical composition

Authors/Composition	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**K_2O**	**SO_3**	**TiO_2**
Huajie Liu et al.[123]	98.7	0.01	0.01	0.02	-	-	-
J. Palaniappan[124]	87.91	4.70	0.94	0.14	0.25	0.09	0.15
S.A.Alftessi et al.[125]	99.5	0.35	0.09	0.01	-	-	0.002
R.S Rashid et al.[126]	97.32	1.36	0.84	0.03	0.06	-	-
N.M. Azreen et al.[127]	97.32	1.36	0.84	0.03	0.06	0.02	0.08
S.E Mousavi et al.[128]	89.01	5.18	1.03	0.34	1.46	0.14	1.40
O.A. Olasupo et al.[129]	95.8	0.4	0.4	0.6	-	-	-
L. Sing Wong et al.[130]	89.00	5.166	1.030	0.33	1.46	0.14	1.402

The sand-casting process involves five steps (figure 2.6). First, mold fabrication with the help of silica sand, binder, and moister. Then, metal or alloy is heated to a liquid state and poured through a sprue into the mold cavity. The molten alloy/metal solidifies in the mold and after a few hours of cooling, the cast product is removed from the mold. The remaining sand is reused to make after a certain screening process. The cast product moved to the secondary process such as machining etc[131].

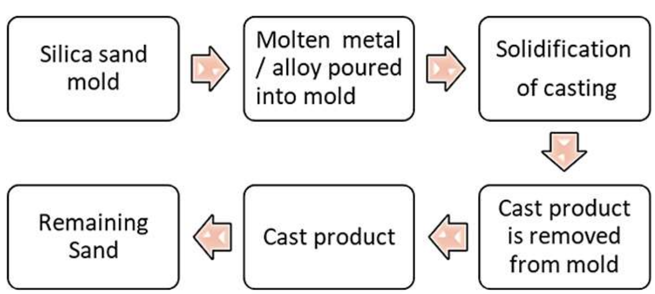

Figure 2.6: Sand casting process

2.6.4 Properties of sand mold[132]

- **Refractoriness**: Refractoriness describes a capacity to endure extreme heat without degrading or fusing. Sand with good refractoriness withstand exposure to hot, molten metal otherwise it may burn at high temperatures.
- **Chemical resistivity:** The chemical resistance of molding sand, which prevents it from reacting or combining chemically with molten metal and also creates pathways for potential foundry materials reuse, is crucial.
- **Permeability:** Permeability is defined as the rate of flow of air through a standard mold sample under standard conditions, and is termed a permeability number.
- **Cohesiveness:** Cohesiveness is the term used to describe how well sand particles adhere to one another.
- **Flowability:** Flowability may be explained by the molding sand's effective ability to condense to a stable density. The flowability of sand/powders is not an intrinsic attribute; it also depends on the stress condition, the tools being used, and the handling technique, in addition to the physical characteristics (such as form, particle size, humidity, etc.
- **Collapsibility:** The capacity of the sand mixture to collapse under pressure. Greater mold collapsibility enables the metal casting to shrink freely as it hardens without running the danger of hot tearing or cracking.
- **Strength:** Green strength refers to the durability of sand in its green or wet form or the dry strength possessed by the sand in its dry or baked state is called dry strength. When the pattern is taken from the molding box or during the pouring of metal, a mold with sufficient strength maintains its shape and resists collapsing.
- **Adhesiveness:** To adhere to the sides of the molding boxes and prevent falling out into the box, sand should have a strong enough an adhesiveness.

2.6.5 Advantages of sand-casting process[121]

- Low cost
- Dimension flexibility
- Component flexibility
- Wide range of metal/alloy

Silica sand is the main ingredient in mold processing, with silica sand some minor constituents are also added to develop a sand mold. The basic mold ingredient such as:

- Silica sand (Natural or synthetic)
- Binder (organic or inorganic)
- Moisture
- Additives

Sand grain bonding capability is based on the binding agent, that develops bonding between sand grains. Commonly used binders in the foundry industries are bentonite, resins, sodium silicate, furan resin, phenolic, oils, etc. Additives are added during the molding process to improve the mold properties most common additives used are wood flour, cereal binder, oats, etc other additives are iron oxide, which is added to increase mold strength and decrease erosion of the mold during steel casting. Various researchers have studied the effect of basic mold ingredients on the behaviour of mold properties (compressive strength, shear strength, hardness, permeability, toughness, etc)[133–139], casting defects (blow-holes, pinhole porosity, poor surface finish, dimensional variation, shrinkage cavities, scabs and rat tails, slag inclusions, misruns, etc)[140,141]. C. Saikaew et. al[122] reported the green compressive strength and permeability are 53,090 N/m^2 and 30 AFS with a combination of 93.3% sand, 5% bentonite, and 1.7% water. S. Guharaja et. al[142] observed that green shear strength, permeability, and mold hardness are 950g/cm^2, 235, and 80 respectively within the range of 2-6% moisture. Y. Chang et al. reported that optimum green strength at the ratio of 0.33 of moisture to bentonite and also observed that the flowability decreased as the moisture content increases[143]. Himanshu Khandelwal et al. reported that optimum mold properties such as compressive strength, and shear strength are 14.80kg/cm^2 and 16.44 kg/cm^2 with the combination of 2% - 4% alkyl resin binder using 40 GFN sand after 4 h curing time [144]. Due to its widespread availability, superior performance, and economic advantages, silica sand has historically been one of the most popular molding materials. However, other issues are now forcing metal casters to consider alternate materials. Potential supply concerns are being brought about by the expansion of silica sand's rival uses in fracking, industrial glass, and foundries in emerging countries. Additionally, to comply with the new respirable silica laws, protect workers, and reduce additional compliance expenses related to the usage of silica sand, foundries are required to look into substituting silica sand with non-silica alternatives. Many researchers study the alternative of silica sand in foundry applications such as Karthick Srinivasan et al. [145] made an effort to use biomass ash as mold material in the foundry industry and observed that the mold prepared by the combination of biomass ash and silica sand shows the satisfactory result to replace silica sand partially in the foundry industry. Patrick et al.[146] studied the effect of ant hill powder and groundnut shell ash as a binder and observed that the addition of groundnut shell ash and ant hill powder up to 14% and 30% respectively is feasible in the foundry application J. Palaniappan [124] made an effort to use coal fly ash in the foundry industry and observed that 20% fly ash addition in silica sand show satisfactory result to use as mold material in the foundry industry. P. Srinivasa Rao and Birru [147] made an effort to use molasses and fly ash as additives and observed that with increased molasses and fly ash percentage in green sand, mold properties enhanced.

Adeosun et al.[148,149] made an effort to use aluminum dross in the foundry industries to replace silica sand and from various tests, they observed that aluminium dross can partially replace silica sand. P. Karunakaran et al.[150] made an effort to replace natural silica sand with the sugar industry fly ash in the foundry industry for aluminium casting, for this they used to perform a series of tests to justify the suitability of sugar industry fly ash as a mold material and the process parameters are % of sugarcane fly ash and % of bentonite. From the observation of various tests, they concluded that sugarcane fly ash (up to 24%) can partially replace silica sand as a mold material. Narasimha Murthy et al.[151] have used granulated blast furnace slag and the combination of GBF slag with silica sand as a mold material. An alloy A356 was cast in three different molds and the cast product gone through various examinations such as metallographic evaluation, hardness studies, tensile testing, compression testing, and Charpy Impact testing which reveal the structural property of the cast product. Based on the result obtained from various examinations they concluded that GBF slag mold produced the casting with the improved structural property. J. Rao and Murthy [152] made an effort to replace silica sand in the foundry industry with granular blast furnace slag. The slag mold is used for the casting of gray cast iron and A356 alloy with the Nishiyama process or Fe-Si process. The process parameters considered are %Fe-Si powder, hardening time, sodium silicate and observed from a series of tests that there is variation in the mold properties as the process parameters varied and concluded that the cast product of GBF slag as mold materials shows good surface finish, no mold wall collapse, no fusing, as well as no dripping of mold ingredient, occur. This is evident that GBF slag can replace silica sand in the foundry industry. Narasimha Murthy et. al [153] made an effort to use industrial waste such as Ferro-chrome slag in the foundry industry and found that the physical and chemical nature of cast products depends on the mold material. In their investigation, they took silica sand and the combination of sand with the

Ferro-chrome slag as mold materials, cast product and mold gone through various examinations such as mold temperatures, microstructure evaluation, SDAS analysis, hardness survey, compression, tensile, and impact properties. From the result of various tests, they concluded that slag mold shows a satisfactory result to replace conventional sand. Narasimha Murthy and Rao [154–156] made an effect to use Fe-Cr slag in the foundry industry to replace silica sand as the mold material. In these works, they used sodium silicate as an additive with the CO_2 process to make a mold of silica sand, Ferro-chrome sand, and a combination of Ferro- chrome slag with silica sand. They investigated the series of tests of the sand particle, slag particle, and molds and observed that Ferro-chrome slag with 15s CO_2 gassing time and 8% sodium silicate can partially or fully replace sand in the foundry application. G.L. Liu et al.[157] found that variations in mold wall thickness and mold materials, change the structural property of casting, and morphology of cast product is modified by using strontium and other elements. They used mold sand such as quartz, alumina, and chromite, to examine the cast product respectively. They found that cooling speed influence the microstructure and mechanical property and also variation in the width of the wall influence mechanical parameter such as elongation as well as tensile strength. Nilza Justiz-Smith et al. [158] made an effort to use red mud as a mold material in the foundry industries. From the investigation of cast microstructure and the volume fraction of porosity in aluminum casting, they observed that red mud can partially replace sand in the foundry industries. Wasiu Ajibola et al.[159] used different mold materials to explain the variation in the properties of cast 6063 Al alloy and found that the property of cast product varies with the variation in the mold material. S.G. Shabestari et al.[160] observed that the properties of A356 alloy are affected by the increase of copper content in the aluminum-silicon alloy system. In aluminium alloy copper content varied from 0.2% - 2.5 wt.% and solidified in different molds such as cast-iron mold, a graphite mold, sand mold, and copper mold, as the mold changed solidification condition also changed. They studied the microstructure, hardness, tensile strength, etc. of an alloy at different solidification conditions, as well as heat-treated and not heat-treated conditions. They found an alloy of 1.5 wt.% copper shows the best mechanical properties in a graphite mold. Peije Li et al.[161] investigated the structure of an alloy after remelting the cast. They cast an aluminum-silicon alloy into the different molds such as sand and metallic mold, the cast was remelted to the temperature of 720^{o}C to 1050^{o}C and also cooled at different cooling rates to pouring temperature and then cast again into the different molds such as metallic and sand mold. They observed that the cooling and solidification rate is decreasing and finally they observed an optimum remelting temperature of 1050 ^{o}C at which the modified structure at all cooling and solidification rate. Santosh M V et al.[162] made an effort to estimate the properties of cast products of different casting techniques such as die casting, centrifugal, and sand casting, and observed that the die casting technique shows better properties with respect to sand and centrifugal casting. Sumaiya Shahria et al.[163] made an effort to reuse the used molding sand in the aluminum casting, with the variation in the bentonite percentage and moisture percentage they observed that 5% bentonite and 5% water in the sand mold shows the least casting defects. A.V. Adedayo et al.[164] found that mold heat capacity plays an important role in the morphology of the microstructure of cast products. They change the percentage of Fe filing in the sand mold and observed that with the variation in the mold heat capacity, it is possible to change the microstructure, tensile properties, hardness and toughness of cast product. A. H. Ahmad et al. [165]used direct thermal method to cast A356 aluminum alloy in copper mold with variation in pouring temperature and holding time. They observed the spherical microstructure at lower pouring temperature and also concluded that in direct thermal method the combination of temperature and holding time plays a significant role in the structure of cast product.

Charnnarong Saikaew et al.[166] investigate the variation of bentonite and water percentage in used molding sand and observed that the molding properties such as green compressive strength are 53,090 N/m^2 and optimum permeability is achieved at 5% bentonite and 1.7% water with the rest of the used molding sand. S. Guharaja et al. (2006)[167] used Taguchi's method to optimize the sand casting parameters such as moisture content, green strength, mold hardness, and permeability number and observed the significant effect on the casting defects.

2.7 Summary and Outlook

In this chapter, the generation, characterization, and application of solid waste such as blast furnace slag, ferrochrome slag, red mud, and conventional sand such as silica sand, and olivine sand are discussed in detail. The basic extraction process, phase transformation, and chemistry of slag also have been addressed. The application of such solid waste in various sectors such as cement production, road construction, extraction of metals, and leachent add value to this waste. As the demand for iron, steel, aluminium, etc increases, which tends the generation of theses waste, leads to environmental hazards. The 100% utilization of this waste is one of the major challenges facing developing and developed countries. Sand casting has a wide range in metal and alloy casting, in this metal/alloy melts and is poured into the sand mold where it solidifies, and after solidified the metal/alloy cast product is removed from the mold. The various mold ingredient affects the mold properties such as a binder, grain fineness number (GFN), and moisture. The quality of molding materials required cannot be described based on physical properties. These bulk properties have significance on the quality of mold such as erosive force and pressure of the liquid metal. The global consumption of silica sand is increasing due to its wide application in the foundry, ceramics, construction industries, etc., which is a serious threat to the environment.