What is Silica?

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Introduction

Silica is the name given to a group of minerals composed of silicon and oxygen, the two most abundant elements in the earth's crust. Silica is found commonly in the crystalline state and rarely in an amorphous state. It is composed of one atom of silicon and two atoms of oxygen resulting in the chemical formula SiO_2

Sand consists of small grains or particles of mineral and rock fragments. Although these grains may be of any mineral composition, the dominant component of **sand** is the mineral quartz, which is composed of **silica** (silicon dioxide). Other components may include aluminium, feldspar and iron-bearing minerals. **Sand** with particularly high **silica** levels that is used for purposes other than construction is referred to as **silica sand** or industrial **sand**.

For a particular source of **sand** to be suitable for glassmaking, it must not only contain a very high proportion of **silica** but also should not contain more than strictly limited amounts of certain metallic elements. **Silica sand** is also normally required to be well-sorted, i.e. to have grains of an approximately uniform size. Most sources of **sand** used by the construction industry do not satisfy these requirements and are not, therefore, suitable for glassmaking.

Industrial uses of silica sand depend on its purity and physical characteristics. Some of the more important physical properties are: grain size and distribution, grain shape, sphericity, grain strength and refractoriness.

What is Industrial Sand (silica sand)

Industrial sand is a term normally applied to high purity silica sand products with closely controlled sizing. It is a more precise product than common concrete and asphalt gravels. Silica is the name given to a group of minerals composed solely of silicon and oxygen, the two most abundant elements in the earth's crust. In spite of its simple chemical formula, SiO2, silica exists in many different shapes and crystalline structures. Found most commonly in the crystalline state, it also occurs in an amorphous form resulting from weathering or plankton fossilization.

For industrial and manufacturing applications, deposits of silica yielding products of at least 95% SiO2 are preferred. Silica is hard, chemically inert and has a high melting point, attributable to the strength of the bonds between the atoms. These are prized qualities in applications like foundries and filtration systems. Quartz may be transparent to translucent and has a vitreous lustre, hence its use in glassmaking and ceramics. Industrial sand's strength, silicon dioxide contribution and non-reactive properties make it an indispensable ingredient in the production of thousands of everyday products.

Some silica sand deposits may cater for the used primarily as metallurgical sand. The copper and zinc at some smelter uses the sand as a fluxing agent which, in the molten state, reacts with various impurities in the ore and produces a slag. The slag is drawn off with the impurities, leaving a more refined metal behind.

Silica sands have a large number of other industrial uses depending on their characteristics.

- **production of glass**
- **foundry sand**
- **ceramics**
- **sandblasting and other abrasives**
- **building products**
- **filler and extender**
- **production of silicon and silicon carbide**
- **pigments**
- **hydraulic fracturing and propping in the oil industry**
- **ultra high silica products in the electronic and fibre optic industries, fused silica, silicone products**
- **water filtration**

The first industrial uses of crystalline silica were probably related to metallurgical and glass making activities in three to five thousand years BC. It has continued to support human progress throughout history, being a key raw material in the industrial development of the world especially in the glass, foundry and ceramics industries. Silica contributes to today's information technology revolution being used in the plastics of computer mouse and providing the raw material for silicon chips. Although glassmaking and foundry uses predominate, numerous minor uses are based on either the chemical purity or physical properties of the **sand** (such as grain-size distribution or grain shape). These include ceramics, water filtration, fluidized-bed furnaces and chemical manufacture. Owing to the demanding specifications required for each application, **silica sand** for glassmaking is distinct from that used for other purposes. In addition to glassmaking, its other major use is in moulds for the foundry industry.

Geology and occurrence of industrial silica

Silica sand is an industrial term used for sand or easily disaggregated sandstone with a very high percentage of quartz (silica) grains. Quartz is the most common silica crystal and the second most common mineral on the earth's surface. It is found in almost every type of rock; igneous, metamorphic and sedimentary. While quartz deposits are abundant, and quartz is present in some form in nearly all mining operations, high purity and commercially viable deposits occur less frequently. Silica sand deposits are most commonly surface-mined in open pit operations, but dredging and underground mining are also employed. Extracted ore undergoes considerable processing to increase the silica content by reducing impurities. It is then dried and sized to produce the optimum particle size distribution for the intended application.

Silica sand may be produced from both unconsolidated sands and crushed sandstones. The sand is a product of mechanical and chemical weathering of quartz-bearing igneous and metamorphic rocks such as granites and some gneiss. Erosion and chemical weathering break down the less stable minerals such as feldspars and release the more stable ones such as quartz and zircon. The stable mineral fragments are transported and redeposited in water. Wave and stream action may further modify the deposits by sorting and washing until a relatively pure deposit of silica sand remains.

Silica exists in nine different crystalline forms or polymorphs with the three main forms being quartz, which is by far the most common, **tridymite** and **cristobalite**. It also occurs in a number of **cryptocrystalline** forms. Fibrous forms have the general name **chalcedony** and include semi-precious stone versions such as agate, onyx and carnelian. Granular varieties include **jasper** and **flint.** There are also anhydrous forms - **diatomite** and **opal.**

Quartz is the second most common mineral in the earth's crust. It is found in all three of the earths rock types - igneous, metamorphic and sedimentary. It is particularly prevalent in sedimentary rocks since it is extremely resistant to physical and chemical breakdown by the weathering process. Since it is so abundant, quartz is present in nearly all mining operations. It is present in the host rock, in the ore being mined, as well as in the soil and surface materials above the bedrock, which are called the overburden.

Most of the products sold for industrial use are termed silica sand. The word "sand" denotes a material whose grain size distribution falls within the range 0.06-2.00 millimetres. The silica in the sand will normally be in the crystalline form of quartz. For industrial use, pure deposits of silica capable of yielding products of at least 95% SiO_2 are required. Often much higher purity values are needed. Silica sand may be produced from sandstones, quartzite and loosely cemented or unconsolidated sand deposits. High grade silica is normally found in unconsolidated deposits below thin layers of overburden. It is also found as "veins" of quartz within other rocks and these veins can be many metres thick. On occasions, extremely high purity quartz in lump form is required and this is produced from quartzite rock. Silica is usually exploited by quarrying and it is rare for it to be extracted by underground mining.

Physical and chemical properties

The three major forms of crystalline silica -quartz, tridymite and cristobalite- are stable at different temperatures and have subdivisions. For instance, geologists distinguish between alpha and beta quartz. When low temperature alpha quartz is heated at atmospheric pressure it changes to beta quartz at 573^{o}C. At 870^{o}C tridymite is formed and cristobalite is formed at 1470^{o}C. The melting point of silica is 1610^{o}C, which is higher than iron, copper and aluminium, and is one reason why it is used to produce moulds and cores for the production of metal castings.

The crystalline structure of quartz is based on four oxygen atoms linked together to form a three-dimensional shape called a tetrahedron with one silicon atom at its centre. Myriads of these tetrahedrons are joined together by sharing one another's corner oxygen atoms to form a quartz crystal.

Quartz is usually colourless or white but is frequently coloured by impurities, such as iron, and may then be any colour. Quartz may be transparent to translucent, hence its use in glassmaking, and have a vitreous lustre. Quartz is a hard mineral owing to the strength of the bonds between the atoms and it will scratch glass. It is also relatively inert and does not react with dilute acid. These are prized qualities in various industrial uses.

Depending on how the silica deposit was formed, quartz grains may be sharp and angular, sub-angular, sub-rounded or rounded. Foundry and filtration applications require sub-rounded or rounded grains for best performance.

Processing technologies

Silica deposits are normally exploited by quarrying and the material extracted may undergo considerable processing before sale. The objectives of processing are to clean the quartz grains and increase the percentage of silica present, to produce the optimum size distribution of product depending upon end use and to reduce the amount of impurities, especially iron and chromium, which colour glass .

To meet these tight specifications, the **sand** often has to be subjected to extensive physical and chemical p**rocessing**. This involves crushing, screening and further adjusting the grain-size distribution, together with removing contaminating impurities in the **sand** and from the surface of the individual quartz grains. The presence of metallic oxides in glassmaking sands usually results in coloured glass. If iron is present, the resulting glass is coloured green or brown. The iron level is consequently the most critical parameter in determining whether a particular **sand** can be used to make clear glass. Sands used to manufacture colourless glass are therefore likely to be processed further by methods such as acid leaching, froth flotation or gravity separation. Figure 1 illustrates the range of iron level permitted in each of the grades of **silica sand**.

FIGURE 1

Glass	Iron content (%)
Crystal glass	0.00
Borosilicate glass	0.05
Optical glass	0.10
Colourless containers	0.15
Clear flat/float glass	0.20
Coloured containers	0.25
Insulating fibres	0.30

Percentage of iron (as ferric oxide)
Source: BS 2975.

Ranges of acceptable iron content in silica sand

In ascending order of permitted iron content, the three most commonly produced categories of glass are:

(a) colourless container glass (or `flint' glass);
(b) clear flat glass (or `float' glass); and
(c) coloured container glass.

These are also the most significant of the various applications for **sand** from the quarries relating to this merger.

Industrial Sand Applications

Glassmaking: Silica sand is the primary component of all types of standard and specialty glass. It provides the essential SiO2 component of glass formulation and its chemical purity is the primary determinant of colour, clarity and strength. Industrial sand is used to produce flat glass for building and automotive use, container glass for foods and beverages, and tableware. In its pulverized form, ground silica is required for production of fibreglass insulation and reinforcing glass fibres. Specialty glass applications include test tubes and other scientific tools, incandescent and fluorescent lamps, television and computer CRT monitors.

Grades of silica sand for glassmaking

The glass industry has established different standard specifications for the **silica sand** intended for seven types of glass. The requirements for these grades of **silica sand** are set out in BS 2975:1988, British standard methods for sampling and analysis of glassmaking **sand** (BS 2975) and cover the following applications:

Glass Types	Quality
Optical and ophthalmic glass	Grade A
Tableware and lead crystal glass	Grade B
Borosilicate glass	Grade C
Colourless (or clear) container glass	Grade D
Clear flat glass	Grade E
Coloured container glass	Grade F
Glass for insulating fibres	Grade G

BS 2975 gives detailed chemical and physical specifications for each of these grades of **silica**/glass **sand**. These specify parameters such as:

(a) minimum **silica** levels;
(b) maximum levels of aluminium, iron, chromium, copper, cobalt, nickel and vanadium;
(c) maximum alkali levels;
(d) maximum losses on heating; and
(e) particle size distributions.

The amounts by which many of these parameters are permitted to vary between deliveries are also specified. Normally ranging between 0.1 and 0.5 mm in diameter, that in the case of glassmaking sands.

BS 2975:1988, British standard methods for sampling and analysis of glass-making sands, British Standards, 1988.

Metal Casting: Industrial sand is an essential part of the ferrous and non-ferrous foundry industry. Metal parts ranging from engine blocks to sink faucets are cast in a sand and clay mould to produce the external shape, and a resin bonded core that creates the desired internal shape. Silica's high fusion point (1760°C) and low rate of thermal expansion produce stable cores and moulds compatible with all pouring temperatures and alloy systems. Its chemical purity also helps prevent interaction with catalysts or curing rate of chemical binders. Following the casting process, core sand can be thermally or mechanically recycled to produce new cores or moulds.

Metallurgical: Industrial sand plays a critical role in the production of a wide variety of ferrous and non-ferrous metals. In metal production, silica sand operates as a flux to lower the melting point and viscosity of the slag to make them more reactive and efficient. Lump silica is used either alone or in conjunction with lime to achieve the desired base/acid ratio required for purification. These base metals can be further refined and modified with other ingredients to achieve specific properties such as high strength, corrosion resistance or electrical conductivity. Ferroalloys are essential to specialty steel production, and industrial sand is used by the steel and foundry industries for de-oxidation and grain refinement.

Chemical Production: Silicon-based chemicals are the foundation of thousands of everyday applications ranging from food processing to soap and dye production. In this case, SiO2 is reduced to silicon metal by coke in an arc furnace, to produce the Si precursor of other chemical processes. Industrial sand is the main component in chemicals such as sodium silicate, silicon tetrachloride and silicon gels. These chemicals are used in products like household and industrial cleaners, to manufacture fiber optics and to remove impurities from cooking oil and brewed beverages.

Building Products: Industrial sand is the primary structural component in a wide variety of building and construction products. Whole grain silica is put to use in flooring compounds, mortars, specialty cements, stucco, roofing shingles, skid resistant surfaces and asphalt mixtures to provide packing density and flexural strength without adversely affecting the chemical properties of the binding system. Ground silica performs as a functional extender to add durability and anti-corrosion and weathering properties in epoxy based compounds, sealants and caulks.

Paint and Coatings: Paint formulators select micron-sized industrial sands to improve the appearance and durability of architectural and industrial paint and coatings. High purity silica contributes critical performance properties such as brightness and reflectance, color consistency, and oil absorption. In architectural paints, silica fillers improve tint retention, durability, and resistance to dirt, mildew, cracking and weathering. Low oil absorption allows increased pigment loading for improved finish color. In marine and maintenance coatings, the durability of silica imparts excellent abrasion and corrosion resistance.

Ceramics & Refractories: Ground silica is an essential component of the glaze and body formulations of all types of ceramic products, including tableware, sanitary ware and floor and wall tile. In the ceramic body, silica is the skeletal structure upon which clays and flux components attach. The SiO2 contribution is used to modify thermal expansion, regulate drying and shrinkage, and improve structural integrity and appearance. Silica products are also used as the primary aggregate in both shape and monolithic type refractories to provide high temperature resistance to acidic attack in industrial furnaces.

Filtration and Water Production: Industrial sand is used in the filtration of drinking water, the processing of wastewater and the production of water from wells. Uniform grain shapes and grain size distributions produce efficient filtration bed operation in removal of contaminants in both potable water and wastewater. Chemically inert, silica will not degrade or react when it comes in contact with acids, contaminants, volatile organics or solvents. Silica gravel is used as packing material in deep-water wells to increase yield from the aquifer by expanding the permeable zone around the well screen and preventing the infiltration of fine particles from the formation.

Oil and Gas Recovery: Known commonly as proppant, or "frac sand," industrial sand is pumped down holes in deep well applications to prop open rock fissures and increase the flow rate of natural gas or oil. In this specialized application round, whole grain deposits are used to maximize permeability and prevent formation cuttings from entering the well bore. Silica's hardness and its overall structural integrity combine to deliver the required crush resistance of the high pressures present in wells up to 2,450 meters deep. Its chemical purity is required to resist chemical attack in corrosive environments.

Recreational: Industrial sand even finds its way into sports and recreation. Silica sand is used for golf course bunkers and greens as well as the construction of natural or synthetic athletic fields. In golf and sports turf applications silica sand is the structural component of an inert, uncontaminated, growing media. Silica sand is also used to repair greens and to facilitate everyday maintenance like root aeration and fertilization. The natural grain shape and controlled particle size distribution of silica provides the required permeability and compaction properties for drainage, healthy plant growth and stability.

Scope for substituting different grades of silica glass

Sand suitable for one use can normally be used for any other application with a higher permitted level of iron. Thus, flint glass **sand** can be used to make float glass or coloured-container glass (since iron can be added to the batch if needed to produce the required colour). As sands with lower levels of iron usually command a premium price, this may not be economically viable unless there are compensating savings, say, in the form of lower transport costs than an alternative quarry.

On the other hand, if a glassmaker wished to use **sand** with a higher level of iron for a lower-iron-level application, the quarry would have to introduce additional **processing**. This might, for example, take the form of acid leaching to remove deposits of iron from the surface of the grains of **sand**. The extent of the capital investment and operating costs needed to do this would determine whether it was an economic proposition. In some locations, it might not be possible for the quarry operator to secure planning permission for the additional plant. Where the iron content occurs as inclusions within the grains, it is often difficult for a quarry operator to reduce the iron specification significantly. Consequently, much **sand** suitable for coloured-glass containers is not capable of being processed to meet the requirements for float glass or flint glass.

It is sometimes possible to produce a number of different grades of **silica sand** from a single quarry by selective quarrying of different parts of the deposit.

Cleaning the quartz grains and increasing silica content is achieved by washing to remove clay minerals and scrubbing by attrition between particles. Production of the optimum size distribution is achieved by screening to remove unwanted coarse particles and classification in an upward current of water to remove unwanted fine material. Quartz grains are often iron stained and the staining may be removed or reduced by chemical reaction involving sulphuric acid at different temperatures. Impurities present as separate mineral particles may be removed by various processes including gravity separation, froth flotation and magnetic separation. For the highest purity, for electronics applications, extra cleaning with aggressive acids such as hydrofluoric acid combined with thermal shock may be necessary.

After processing, the sand may be dried and some applications require it to be ground in ball mills to produce a very fine material, called silica flour. Also, quartz may be converted to cristobalite in a rotary kiln at high temperature, with the assistance of a catalyst. Some specialist applications require the quartz to be melted in electric arc furnaces followed by cooling and grinding to produce fused silica.