SILLIMANITE MINERALS

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The sillimanite group consists of three minerals andalusite, kyanite and sillimanite itself, all with the same chemical composition but with different crystal structures and physical properties. Both andalusite and sillimanite are orthorhombic, but kyanite is triclinic. Andalusite has a hardness of 7.5, sillimanite 6-7 and kyanite varies between 5-7. Andalusite has the lowest density at 3.16-3.2, sillimanite is slightly higher at 3.23-3.27 but kyanite is significantly higher at 3.56-3.67. The chemical formula is normally written as $Al_2O_3.SiO_2$ with a theoretical composition of 62.93% alumina and 37.07% silica.

All of the sillimanite minerals convert to mullite (about 88%) and silica (about 12%) on calcining or heating at temperatures of 1,250° to 1,500°C. Each of the minerals converts at a different temperature, with kyanite needing the least heat and sillimanite the most. Mullite is extremely refractory, has a small coefficient of expansion, is abrasion- and slag-resistant. Because it commonly forms intergrowths of needle-shaped crystals, products made from mullite have good creep resistance.

Since mullite is the mineral component that is sought after by the refractory industry, the sillimanite minerals could almost be regarded as 'mullite ore'. Mullite, with a theoretical chemical formula of $3Al_2O_3.2SiO_2$, does occur in nature and takes its name from the type locality on the island of Mull off the west coast of Scotland. In the case of andalusite, mullitisation begins at about 1,250ºC. About 50% of the andalusite is converted to mullite and glass as the temperature is raised to 1,350ºC. Only 10% andalusite is left at 1,400º and complete mullitisation occurs by about 1,600º. This is under test conditions where there is a rise in temperature of 120ºC per hour and two-hour soaking at various selected temperatures.

Sillimanite gave its name to the group mainly because a large portion of supply in the early years of the industry was sillimanite from India. It was also difficult until recent times to distinguish between sillimanite and mullite and it was believed that the product of calcination was sillimanite rather than mullite, which is now known to be the case. In the US, kyanite was the predominant mineral produced and the term 'kyanite and related minerals' is commonly used to describe the group in that country.

While the three minerals that make up the group have the same chemical composition, their physical properties are different. Most importantly, sillimanite and andalusite increase irreversibly in volume by only about 4% and 6% respectively on calcining. They can be used directly in refractories without calcining because the small volume increase can be accommodated by the users and can be beneficial. The minerals are essentially being calcined during use and the expansion can result in very tight fitting-refractory linings. Kyanite, on the other hand, increases in volume by 16-18% on calcining. This expansion is used as an advantage in some instances where raw kyanite is added to a refractory mix to counteract the shrinkage on firing of other components, notably clays.

In other refractory applications, kyanite needs to be calcined prior to incorporation into refractory products. Conversion to mullite and silica usually takes place at temperatures of 1,250° to 1,500°C and the mullite formed is then stable up to about 1,800°C.

Although the three minerals that make up this group have different properties, all of them are primarily used as refractories and depend on the steel industry for most of their demand. The health of the steel industry and changes in technology that effect the usage of

refractories are by far the greatest influence on the consumption of these products.

With this in mind it is worth briefly considering the health of the steel industry. In 2001, World crude steel production fell by about 0.9% from 847 Mt to 840 Mt. However, there were some significant geographic differences. Production in North America fell by more than 11% and the steel industry in the US, in particular, is experiencing major problems, with December production figures more than 16% below the same month in 2000. Several of the large steel producers are experiencing financial problems with some in Chapter 11 bankruptcy, which in turn has resulted in some refractories manufacturers suffering the same fate.

The picture in Europe is slightly better, with EU production down by 2.8% over the year as a whole but the December figures show a decline of 9%. It is also notable that comparing December to December, of the largest producers German production fell by over 11%, Italian by 6.4%, French production by 22%, and Spanish, UK and Belgian by 8.6-8.8%. There were also significant declines in most of Eastern Europe and the FSU as well as in South America and Oceania. However, with the changing geography of steel production, there were increases in the Middle East, Africa and, most notably, Asia.

Asian production rose by 4% year on year and 3.7% December to December. Production in Japan fell by 3.4% year on year and 9% December to December. However, this fall was more than compensated for by an increase in production from the largest Asian producer, China, where production rose by 11.9% year on year and 13.8% December to December. Production also rose in some other countries in the region including South Korea and India.

Each of the sillimanite minerals has its own specific niche in the industry because of their different physical properties and their relative availability, and each one is dealt with separately below.

Andalusite

Although andalusite is a common mineral, commercial production is limited to only a few countries. The largest producer is South Africa, followed by France, and all of the current production from these two countries is controlled by a single company, the French based Imerys Group. Total production from these two countries was 230,000 t in 2001, about 20,000 t less than revised figures for 2000, which were increased to 250,000 t from initial estimates. Of this about 170,000 t was produced in South Africa and the balance in France. Production from China is still estimated to be of the order of 10,000 t, all for use within China, although it is difficult to get reliable figures.

Most of the decrease in demand for andalusite occurred in Europe, with a significant decline in the UK throughout the year due largely to the closure of the Manuel works of Vesuvius and transfer of production equipment to a plant in Poland. During the changeover, significant sales of andalusite-bearing refractories have been lost. In the last quarter of the year, consumption of andalusite fell off in the rest of Europe, reflecting a drop in steel production.

The main markets for andalusite are in Europe, South Africa and Asia, particularly Japan. Much of the decline in consumption during 2001 occurred in Europe, with the market estimated to have fallen to about 140,000 t, significantly below its peak levels. With declining steel production and changes in refractory practice such as a move towards monolithic spinel linings replacing andalusite brick in ladles, the consumption of andalusite may continue to decline in the region. South Africa is the second-largest consumer with an estimated market of about 50,000 t, mainly because of local availability enhancing the competitive position of andalusite refractories, although some finished refractory products containing andalusite may be exported.

The market in Asia is estimated to be about 40,000 t/y. Much of this is in Japan, Korea and Taiwan, and there is significant competition from other aluminosilicate raw materials,

notably high-alumina calcined clays and bauxites from China. In China itself, the wealth of locally produced refractory raw materials, as well as a growing local refractories-producing industry, means that few refractory raw materials are imported for what is one of the largest and fastest-growing steel industries. It is very notable that consumption of andalusite in other regions, most notably North America, is very small, with only a few thousand tonnes of andalusite imported into the US each year.

Forecasts for future production of steel are getting more and more difficult. The effects of tariffs introduced on steel being imported into the US are still to be felt. These will have a relatively small direct effect on imports from Europe, but steel from Asia, that will be most effected may be diverted to compete in European markets at the expense of domestic producers. Longer-term growth in steel production in Europe is not expected to be large.

There is significant production overcapacity for andalusite. Within the Imerys group, total annual capacity is about 350,000 t (80,000 t at Glomel in France and the rest in South Africa), some of which is currently idle, and there is another smaller operation in South Africa, owned by Hernic-Premier Refractories, that is currently idle. However, Andalusite Resources (Pty) Ltd is currently in the process of opening a new 30,000 t/y capacity andalusite mine, with production scheduled to start in mid-2002. Andalusite Resources is more than 80%-owned by Hernic. Much of the plant from the idled Hoogenoeg mine has been transferred to the new site at Maroeloesfontein close to the Rhino mine of Imerys in the Thabazimbi district. Product from the new operation is expected to be a 57-58% alumina material with less than 1% Fe_2O_3 and a grainsize of 0.5-3 mm. In addition, some of the old stockpiles from Hoogenoeg may be exploited for additional material. It may be questionable to open a new mine at a time of significant overcapacity but the company feels that there is a need for a second supplier and that there is a niche for its product in the marketplace.

During 2001, Imerys was in the process of reorganising the range of grades of andalusite that it supplies. This process has not yet been completed and the company has not yet published a modified range of products.

There have been numerous investigation over the years into alternative sources of andalusite, many of which have never proceeded past initial investigations. In the light of current overcapacity there seems little need for new operations. However, there may be opportunities in markets where the use of andalusite is currently limited, remembering that South Africa is a large consumer of andalusite because of its local availability and relatively low delivered price. The usual problem with potential andalusite operations is producing a material with a coarse grain-size and low impurity levels at a competitive price. One project that is at the pilot-testing stage in Peru may have significant potential but few details are being released until the project has advanced further.

Kyanite

In contrast to andalusite, where markets are predominantly in Europe, and South Africa, the principal market for kyanite is in the US, where the only significant Western producer is based. Kyanite Mining Corp. is by far the largest producer of kyanite, with estimated production of about 90,000 t/y. However, the company is privately owned and production figures are withheld. Production capacity is estimated to be of the order of 135,000 t and the company may produce as much as 120,000 t in a good year. It produces both raw and calcined kyanite, with current calcining capacity of about 45,000 t, although a new 80,000 short ton capacity (72,500 t) kiln is in place at the company's Gieseke facility and due to be brought into production soon.

The company's main market is in the refractories industry, where kyanite is used either in the calcined form and commonly sold as mullite, or in its raw form, where its expansion characteristics are utilised to counteract the shrinkage of other components.

most notably clays. However, it has developed other markets, mainly in the US. These include other high- temperature applications in foundry sands, kiln furniture and investment casting, as well as ceramic applications, where its expansion characteristics are again put to good use, and in abrasive and kiln furniture. However, compared with the refractories industries these applications are still relatively minor. While the company exports to 27 countries throughout the world, almost all of the usage outside the US is in refractories.

Elsewhere, production of kyanite is relatively minor, with an estimated 10,000 t/y produce in India, a similar amount in China and up to 15,000 t/y as a by- product of heavy mineral sands operations in the Ukraine. Some production is reported in Zimbabwe and a deposit is being investigated in South Africa.

Sillimanite

Production of sillimanite is now very limited. Production in China is entirely for domestic use and is estimated to be about 15,000 t/y from a number of small operations. Current production in India, once a large producer, is about 10,000 t/y as a by-product of mineral-sand operations. There is also minor and possibly intermittent production in South Africa and Australia.

Calcines and Sinters

Although they are not part of the sillimanite group of minerals as such, there is a range of products commonly referred to as high alumina calcines that are similar in composition to sillimanite minerals and compete in certain markets. These are manufactured from blends of kaolin and bauxite, some of which occur naturally. Compositions can vary from almost pure calcined kaolin at about 47% alumina to just over 70%, close to the theoretical composition of mullite.

The best known of these is the Mulcoa range manufactured by C-E Minerals, a US-based subsidiary of Imerys. The company can produce up to 550,000 t/y of calcined product, made up of three principal grades nominally with alumina contents of 47%, 60% and 70% the proportions of which can be varied depending on the relative market demand. There has been no real change in the operations during the year, although production details have not been released. While the company exports considerable quantities of material, most of its sales are in its home market and, with the decline in steelmaking during 2001, it would be expected that sales will have declined. Estimated production of 60% alumina product was 130,000 t in 2000 and that of 70% alumina was about 40,000 t. With a 16% decline in steel production in the US (comparing December to December) and some steel and refractories companies in financial difficulties, production of calcines may have fallen by a similar amount but it is difficult to be precise.

Similar products are produced elsewhere. About 50,000 t/y are produced in Brazil, almost all for domestic consumption. Significantly, a new operation has been built in China by Aluref that will initially produce up to 30,000 t/y of a similar range, with the possibility of doubling this at a later stage. With strong growth in the large Chinese steel industry, which now has production levels more than 50% larger than the US, much of the initial production may well be consumed in the domestic or regional industry.

Although some of the high alumina calcines and calcined kyanite may be referred to as sintered mullites there are products on the market that may more accurately be described as true mullite. Fused and sintered mullite are generally higher-value products that are essentially pure mullite manufactured from either bauxite and clay or, in the case of higher purity products, alumina and silica. The production of sintered mullite is now quite low, with producers in Japan and the UK exiting the market. Total world production is probably only a few thousand tonnes, having been as high as 30,000 t/y at one time. There is greater production of fused mullite, from the US, Europe and Japan, amounting to a few

tens of thousnds of tonnes annually. These tend to compete in different markets from the sillimanite minerals as they are considerably higher in price and used where their performance justifies the added cost.

Prices

Despite the fall in sales of andalusite and poor markets for many refractory minerals, there have been no significant changes in prices, at least on a list basis. Quoted prices are the same as they were one year ago. This is not uncommon. Prices changes in the industry tend to be infrequent and it is actually rare to see a reduction in list prices. On a cif Rotterdam basis, the price for a 59% alumina South African andalusite would be about €200/t, with some increases in freight costs.

Sillimanite Mineral Prices 2001

Andalusite, 57-59% Al_2O_3 fob, South Africa, bulk, per tonne	€35-170
Andalusite, 58% Al_2O_3, fob, North France, bulk, per tonne	€210
Andalusite, 57% Al_2O_3, fob, North France, bulk, per tonne	€180
Kyanite, fob US, raw, per short ton	US$135-165
Kyanite, fob US, calcined, per short ton	US$238-268
Mulcoa 60, fob Georgia, per short ton	US$143
Mulcoa 70, fob Georgia, per short ton	US$220