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 is 6-7 and the value for 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 and silica (88:12, respectively) on calcining or heating at temperatures of 1,250°C 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, and because it commonly forms intergrowths of needle-shaped crystals, products made from it 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.

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. 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.

As noted above, the three minerals that make up the group have different physical properties. 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. The mullite formed is then stable up to about 1,800°C.

Virtually all of the production of sillimanite minerals is used to manufacture refractories. As such, the demand is dependent on the strength of the refractories industry which is in turn dependent on its consumers and particularly the steel industry, which accounts for about 60-70% of refractory demand. The three minerals of the group have very different markets and are dealt with individually.

Andalusite

Of the sillimanite minerals, andalusite is produced in the greatest volume. Most of the production comes from only two countries, South Africa and France, with only relatively minor quantities from China. A single company controls all of the current production

in both France and South Africa, the French-based Imerys. Total production in 2000 was 230,000 t, with approximately 170,000 t from South Africa and 60,000 t from France. Production of andalusite in China is estimated to have been around 10,000 t, for use within China. Although samples of Chinese andalusite have been distributed, no significant export markets have been established.

Andalusite capacity in South Africa is considerably more than current demand. Imerys owns five andalusite mines in South Africa but the Havercroft mine that it acquired through the purchase of Rhino Minerals in 1999 and the Anref (or Groot Marico) mine are both closed at the moment. The Rhino mine (also known as the Thabazimbi mine), which was also acquired from Rhino Minerals, is operating at well below capacity. The one mine that is still in independent hands is the Hoogenoeg mine owned by Hernic-Premier Refractories. However, the mine remained closed throughout 2000. The company is still investigating the possibility of reopening the mine to produce staurolite for use as an abrasive, mainly for sand blasting. If marketing and development work proves successful, the mine may reopen with andalusite being a co-product with staurolite, which was previously a waste material that had to be removed from the andalusite to reduce the iron content to within specification levels.

In France, there has been little change at the Glomel mine of Imerys, operated by its subsidiary Damrec. Current production is estimated to be about 60,000 t.

Imerys is in the process of reorganising the grades of andalusite that it supplies. It will publish a modified range of products during mid-2001, essentially avoiding duplication of ranges following the consolidation of the mines in South Africa. After the purchase of Rhino, the marketing of their products in Europe was still carried out under a long-term agreement by Europe Minerals BV of the Netherlands, which had formerly been known as Rhino Minerals Europe. However, Imerys acquired the marketing rights during 2000 and now markets the entire range of products from South Africa either through subsidiaries or agents appointed in specific countries.

The largest market for andalusite by far is in Europe. Steel production in Europe rose in 2000 with the notable exceptions of the UK and Netherlands, at least partly reflecting rationalisation of Corus the company formed through the merger of British Steel and Hoogovens. However, the outlook is currently uncertain, with fears that the slowdown in the US economy will have an impact on the global steel industry. Because of this, there is uncertainty about the short-term future demand for andalusite with consumers reluctant to commit to purchase requirements.

Some other trends are also expected to influence the andalusite market. Some steel companies are moving towards the use of alumina spinel linings for steel ladles replacing andalusite brick. This could result in a reduction in demand for andalusite in Europe of around 8,000 t/y or about 5-6% of current European requirements. The practice of using monolithic linings containing alumina and magnesia, which form spinel on calcining during the first heat of the ladle is well established in Japan, but is still in limited use in Europe.

Another significant influence on the andalusite market will be the closure of the Manuel refractory plant in Scotland, owned by Vesuvius. Production of refractory bricks from this plant will stop by the end of 2001. However, brick production is to be transferred to the company's Skawina plant in Poland, which has been producing refractory brick since 1998. The Polish plant's capacity will be increased from its current 10,000 t/y to about 35,000 t/y after the arrival of equipment being transferred from the Manuel Works. The UK and particularly Premier Refractories, which was acquired by Vesuvius, is a large user of

andalusite in its products. Imports of andalusite into the UK are likely to decline significantly although at least some of the demand will simply be moved to Poland, which is likely to increase its imports of andalusite. As much as 60-65% of the production from the Manuel works is exported and it is expected that much of the production transferred to Poland will be for export markets.

Rationalisation of the refractories industry has meant that there are few large diversified producers of refractories left. Those that are left are tending to purchase raw materials centrally and, with globalisation of the industry, large consumers are negotiating purchases for worldwide operations as a single agreement with the same price on an fob basis, either from the South African or French operations. There is also a tendency to work with shorter lead times, with the refractories companies keeping lower stocks and requiring prompt delivery of purchases.

The second largest market for andalusite is South Africa, mainly due to the availability of material locally, which makes it relatively low cost, particularly in relation to imported raw materials. There is also likely to be exports of refractory products, manufactured using andalusite. The Far East is the other significant market, principally in the major steel-producing countries of Japan, Korean and Taiwan, but levels of consumption are well below those in Europe. China is by far the largest producer of steel in the region but tends to use its wide range of domestically produced refractory raw materials including its own modest production of andalusite.

The North American market for andalusite has never been large and annual US imports are only about 5,000 t. This is mainly due to refractories manufacturers developing products based on domestically produced raw materials such as calcined kyanite, and high alumina clay calcines where possible, although there is considerable use of other high alumina materials, particularly calcined bauxite.

There have been no major developments regarding potential new operations. A company is still investigating what appears to be a promising deposit in Peru although it may be some time before a decision is made to proceed. In China, the Delong Group is investigating the possibility of developing a major andalusite deposit in South Hunan Province, although it is reportedly in a remote area.

Kyanite

Production of kyanite is difficult to assess. There is only one large producer, Kyanite Mining Corp., which is based in Virginia, US. The company does not release any production or sales figures, but it is estimated that production is of the order of 90,000 t/y. The company sells both raw kyanite, mainly used in relatively small quantities in refractory mixes to counteract shrinkage of other materials, and calcined kyanite used as a refractory grog. The majority of sales are in the US, but the company also exports significant amounts.

Elsewhere, production of kyanite is quite limited. There is reportedly considerable production capacity in China, but actual production is estimated to be only of the order of 10,000 t/y for local consumption. Similarly, there is about 10,000 t/y of production in India, which was once an important source of kyanite for international markets. In the Ukraine, about 15,000 t/y is being produced as a by-product of titanium mineral sands operations. There is also some production in Zimbabwe.

Sillimanite

Although sillimanite gave its name to the group and has historically been important commercially, output is now limited. Production in China is thought to be about 15,000 t/y from a number of small operations. India was once the main supplier of sillimanite but as reserves declined so did

production, and the current output is about 10,000 t/y as a by-product of mineral sands operations in contrast to the boulder sillimanite that was the basis for the historically important production. There is minor production in Australia, but the main product from the operation is a kaolinised sillimanite with an alumina content of 46-50%.

Calcines and Sinters

These materials are not strictly part of the sillimanite minerals group, but by careful blending of kaolin and bauxite or simply calcining bauxitic clay, a range of products can be produced that are similar in chemical composition to the sillimanite minerals. Materials varying from pure kaolin, at 47% alumina, to just over 70% alumina (roughly equivalent to mullite) are produced.

The best known of these products is the Mulcoa range manufactured by C-E Minerals, a subsidiary of Imerys in the US. There has been little change in production during 2000. The company has a total capacity of about 550,000 t/y of calcined product, which can be varied depending on relative demand for different grades. It is estimated that current annual production of Mulcoa 60 (nominally close to sillimanite mineral composition) is about 130,000 t with a further 40,000 t of Mulcoa 70 (close to mullite composition). The balance is the lower alumina, Mulcoa 47, essentially calcined kaolin. While there has been little change in the market for these products, it should be noted that there has been a decline in US production of steel in the first quarter of the year of close to 14% compared with the same quarter in 2000. However, some sources expect that demand will improve later in the year. The majority of production of Mulcoa products is used domestically, but the company also exports considerable quantities.

There is production of high alumina calcines in other parts of the world, although little if any is traded internationally. In Brazil, an estimated 50,000 t/y of high alumina calcines are produced for domestic consumption.

In China, a new product has been introduced called Reframul, produced by Aluref in Shanxi province and being offered for sale by Jersey Mineral Processing (CMP) which has a 50% shareholding in the venture. Four products are being manufactured, Reframul RM47 (typically 45.1% alumina), RM47NC (a no cristobalite variation on the RM47 grade), Reframul RM60 (typically 62.81% alumina) and Reframul RM70 (typically 68.14% alumina). It is expected that most of the output will be consumed in China. A few thousand tonnes of material has been sold from a pilot-plant operation but the company is now in the process of construction of a full-scale plant. Production was initially scheduled to begin late in 2000 or early 2001, but for various reasons (including the effects of a severe winter) construction has been delayed and is now scheduled for the third quarter of 2001. Initial production capacity will be 30,000 t/y rising to 60,000 t in a second stage of development. Most of the output will be transported to CMP's Tianjin plant for crushing and sizing. Sales will initially be to domestic and possibly Asian customers, but the company has ambitions to export further afield. It remains to be seen how well customers accept it and if it can effectively compete with established products.

Sillimanite Mineral Prices, 1999	
Andalusite, 57-59% Al_2O_3 fob, South Africa, bulk, per tonne	€135-170
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

Although some of the high alumina calcines and even calcined kyanite may be referred to as sintered mullites on occasion there is another category of products that is known as sintered and fused mullites. These products are generally higher-value, essentially pure mullite, manufactured from either bauxite and clay or for higher purities, from alumina and silica. Total world annual production of sintered mullite had been about 30,000 t with a further 50,000 t of fused mullite, mainly in Europe, Japan and North America. During 2000, Imerys purchased one of the largest producers, Keith Ceramic Materials (KCM) of the UK. The purchase was made through its subsidiary, Treibacher of Austria, one of the largest producers of fused alumina that Imerys had acquired only a few months earlier. Subsequently it was decided to stop production of sintered mullite at KCM's plant and concentrate on the production of fused products, specifically fused mullite and mullite zirconia. The closure means that world capacity for sintered mullite will be reduced by about 8,000 t/y, but the company has plans to increase its capacity for fused mullite. The market for sintered mullite had been declining and KCM expected that decline to continue.

Prices

There has been little change in prices during the year. Prices of South African andalusite are now quoted in euros as opposed to dollars. Prices quoted are actually lower than it would appear from previous years, although this is more a reflection of selling prices in the market, as opposed to list prices, rather than an actual reduction in price. 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.