SILLIMANITE MINERALS

By Ted Dickson
TAK Industrial Mineral Consultancy, Gerrards Cross, UK

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 and 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, 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. 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 1,400ºC and complete mullitisation occurs by about 1,600ºC. This is under test conditions where there is a rise in temperature of 120ºC per hour and 2 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.

Although 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 affect the usage of refractories are by far the greatest influences on the consumption of these products and need to be assessed briefly to indicate market conditions.

Steel industry

World crude steel production grew rapidly in 2003 to 965 Mt from 904 Mt in 2002. Much of this increase was due to the continuing surge in growth in production in China, where the average annual growth rate have been over 20%. This growth is continuing, despite predictions that it is unsustainable. It seems likely that these predictions will be correct eventually and that growth rates will have to moderate. China is now the largest producer in the world, with current production of about 220 Mt, greater than even the newly enlarged EU. There was also growth outside China, but at more modest rates. Europe and Asia outside China grew at modest rates, although growth in North America was very small, but improved from the trough at the end of 2001. This has resulted in some improvement in markets for sillimanite minerals, but less than might be expected from the overall growth in steel production. This is partly due to the fact that China has not been a large importer of andalusite or kyanite and relies heavily on locally produced alternatives.

Mineral markets

Although all three of the sillimanite group of minerals have the same chemical composition, they have different physical characteristics and different regional availability. These differences are reflected in the markets served and because of this each of the minerals and high alumina calcines that have similar chemical compositions are dealt with separately below.

Andalusite

Production of andalusite is still dominated by output from two countries, South Africa and France. Total production is estimated to have been about 220-230,000 t from these two countries, with about 60,000 t from France and 160-170,000 t from South Africa. This is slightly lower than the previous year. There is also production in China, but no export sales of Chinese andalusite are known. Production in China may be of the order of 10,000 t and possibly rising because of local demand. However, the material is thought to be high in iron compared with other sources and this limits its applications, especially in international markets.

The dominant supplier of andalusite is Imerys, through its subsidiaries Samrec in South Africa and Damrec in France. Indeed, for a short period up

to 2003, it was the only supplier to world markets, given that Chinese production was limited and only for domestic consumption. Despite consolidation there is still overcapacity. Samrec re-opened its Havercroft mine in July 2003, but at the same time mothballed its Annesley mine. There were no real changes in overall output, with the change in production location being made for operational reasons. The two mines exploit the same deposit but on the opposite sides of a hill. The overall market for Samrec's product was slightly smaller in 2003 and into 2004.

There has been some improvement in European markets and growth in Asian markets. Although China is seen as having significant potential, the main market in Asia is still in Japan with relatively small amounts exported to China. Import taxes into China and the logistics of delivering to the consumers there are not favourable at the moment, making market penetration difficult. The US market has little influence on andalusite sales because it has traditionally been a very small consumer as refractories companies have tended to use locally-produced high alumina clays or calcined kyanite, as well as imported refractory bauxite as alternatives. One change in the structure of marketing the product from Damrec is that the company has formed a joint venture with Europe Commerce for the marketing of products in Europe. Production at its long-established operation in northern France was essentially unchanged during the year.

In 2003, a new supplier, Andalusite Resources, started sales from a deposit within one of the main andalusite mining districts of South Africa. The initial production capacity at the mine, which actually started production at the end of 2002, is 30,000 t/y, although there is the possibility of increasing this to 45,000 t in a relatively short period, should there be sufficient demand for its product. The company has apparently been making inroads into the local markets and is developing export markets.

Chinese production has been reported to be around 10,000 t/y, although there have also been reports of much higher levels of production capacity. In March 2004, a new plant was commissioned at Ku'erle in Xinjiang Province. The plant, operated by Xinjiang Bazhou Yilong Andalusite Mineral Co, has a capacity of 50,000 t/y although there are plans to increase that to as much as 100,000 t within three years. Apart from supplying local refractory markets that are currently very strong because of the dramatic growth rates of the steel industry, the company hopes to develop export markets. One significant problem is the distance from a major port, around 2,500 km, although there is a rail link to Tianjin. The company is looking at the possibility of exporting to Europe via a Western rail route direct to the market. Normag a German-based but Chinese- owned trading company has been appointed exclusive sales agent for Europe. Three grades of product will be produced with alumina contents of 53-59% and iron from 0.7-1.0%. It can be supplied as 0-6 mm, 0.8 mm or 0.1 mm sizes and there has apparently been interest from European consumers.

Kyanite

There has been very little change in the kyanite markets. A single company, US-based Kyanite Mining Corp is the dominant supplier to the industry. Both raw and calcined grades are supplied to markets. Total production is estimated to be of the order of 100,000 t/y, although the company has a greater capacity and there may be some increases in 2004 as domestic markets improve and/or if markets can be developed in the growing Chinese refractories and steel industry. Although its largest market is the domestic US market, the company has been increasing its sales outside the US. As much as 38% of production is exported. Recently, it has been actively targeting the Chinese market, as although China has production of kyanite, the company believes that its products are better performing than the local production and that the Chinese market offers considerable potential to generate new sales. As yet, Kyanite Mining has sold very little to China but hopes to build sales significantly. It is expected that much of this will be in the form of raw kyanite although the company did not specifically indicate that.

China has a wealth of high alumina refractory raw materials and is unlikely to require large quantities of calcined kyanite. However, raw kyanite with good expansion characteristics that can counteract the shrinkage of other refractory materials, specifically clays, has considerable potential. Kyanite mining sells its raw kyanite for this purpose throughout the world, although there are some exports of calcined kyanite.

Production of kyanite outside the US is relatively small. Yet again, China has enormous potential, but relatively minor production. Current estimates are that production is of the order of 20,000 t/y, but it is known that the country is importing US kyanite. There is also about 10,000 t/y of production in India and Bajaj Associates now produces a calcined product referred to as sintered mullite from a 10,000 t/y capacity plant.

There is also some by-product production from mineral sands operations, with a reported 15,000 t/y produced from operations in the Ukraine, and other mineral sands producers have looked at the possibility of extracting a saleable product. Elsewhere, production in Zimbabwe is estimated to be a few thousand tonnes annually. There have been numerous attempts in the past to develop new deposits of kyanite, but the good expansion characteristics of the US kyanite has been difficult to match and a number of developments have failed over the years.

Sillimanite

Although sillimanite gives its name to this group of minerals, its commercial production is now quite limited and international trade that once saw large quantities shipped from India to Europe is now very minor. Essentially there was no real change in the production and consumption of sillimanite during 2003. It has been reported that production in China is about 20,000 t although the potential is far greater and capacity may be as high as 60,000 t/y. In India, about 15,000 t/y are produced, much of it as by-product from mineral sands operations. Some is exported, with Japan as one destination. There is still

some very minor production of sillimanite in Australia from a kaolinised deposit, where sillimanite is a by-product of clay mining.

Clay calcines

Although these are not strictly sillimanite minerals, a range of products with alumina contents similar to the sillimanite minerals may be produced, by calcining blends of clays and bauxite. The best known of these is the Mulcoa range produced by C-E Minerals in Georgia, US. The company, a subsidiary of Imerys, which is also the largest andalusite producer, supplies material with nominal alumina contents of 47%, 60% and 70%, essentially a calcined kaolin, along with a product blended to sillimanite mineral composition and a sintered mullite. Total production is of the order of 550,000 t, including about 130,000 t of 60% and 40,000 t of 70%. Apparently the company is working at or near its current capacity. The products from C-E are renowned for being very consistent materials and considerable quantities are exported throughout the world, including about 80,000 t of all grades to Europe. There is also some production from Brazil, reported to be as high as 50,000 t, largely for domestic consumption. China has emerged in recent years as an alternative source of supply. As reported last year, Aluref and Nanchuan Minerals are both developing operations with similar products to Mulcoa, with capacities of 30,000 t/y and 25,000 t/y respectively. Both have attempted to penetrate export markets in the face of strong domestic competition from other materials such as calcined bauxite. However, with strong local demand for refractories from the booming steel industry, it is likely that domestic markets are providing some demand.

Fused and sintered mullite are more specialised and higher value products than the high alumina calcines, although the calcines and calcined kyanite have been referred to as sintered mullite in some instances. Production of sintered mullite is very limited now, with Nabaltec the only remaining producer in Europe and production elsewhere minimal. Fused mullite production is considerably higher with several tens of thousands of tonnes produced in the US, Europe and Japan. However, this product is considerably more expensive than sillimanite minerals or high alumina calcines and competes in very different markets. In the UK, KCM a long-standing producer of fused and sintered mullite, has stopped production. It had earlier halted output of sintered mullite but now appears to have stopped fusing material too. However, its parent company Treibacher, part of the Imerys Group has extensive fusing capacity in other locations for a variety of products.

Prices

There has been little change in prices for many of the sillimanite minerals during the year, a situation that is not uncommon for such minerals. However, there has been some change in prices of andalusite from South Africa. During the year prices increased to about €150-185/t fob South Africa an increase of €15/t. Because of the strong rand to dollar exchange rates, South African costs have been higher in dollar terms. Freight costs and exchange rate fluctuations have been the main factors governining prices. Freight costs have been higher, but if material is priced in dollars, weakness of the dollar against a number of currencies has, to a certain extent, counteracted this.

Kyanite or high alumina calcines from the US may actually be cheaper in some export markets because of the dollar weakness.