Design rules for avoiding draw horizon damage in deep level block caves

by R.J. Butcher*

Synopsis

Deep level block caving as a mining method is becoming more popular due to the fact that it is the lowest cost per ton underground extraction system. However, many block caves do not achieve their full potential due to draw horizon instability. In this paper five design rules are given to overcome this problem. The design rules described are applicable for slusher and trackless block caves where the operational depths exceed 500 metres.

Introduction

Block caving is described by Laubscher (1994) as the lowest cost underground mining method provided that the extraction layout is designed to suit the caved material and the draw horizon can be maintained for the life of the draw. An examination of this statement shows that not only is correct size and spacing of the draw points essential for efficient extraction, but also that stability of the draw horizon over the full life of draw is essential for the success of the block caving operation. This need for stability is further emphasised by the realization that, due to draw requirements, block cave layouts are relatively inflexible when compared with systems to extract tabular ore bodies. The importance of stability in draw horizons is further highlighted by the long life of the draw level compared to tabular mining methods. In essence the average block cave has a life expectancy of 5-20 years compared with, for example, a scattered mining stope in a tabular gold mine which has a life expectancy of 2 years. If stability problems occur, they are not easily remedied and normally have a severe impact on production. Laubscher (1994) identified 25 parameters that should be considered before the implementation of any cave mining operation. This paper draws from Laubscher's paper and presents five rules which, if properly implemented, will ensure that draw horizon stability is maintained. Slusher and trackless block caving mining methods and the threats to the draw horizon in these operations are described.

Mining methods

Typical layouts for trackless and slusher block caving systems are described by Owen and Guest (1994) and Hartley (1981) and are shown in Figures 1 and 2. The essential features of block caving systems are:

- ➤ a draw horizon or production level where the caved ore will be extracted through draw points;
- ➤ an undercut level whose function is to create a void above the draw horizon to induce the caving process;
- ➤ in the case of a deep-level block cave two undercutting development methods may be used, namely:

Block cave development using a post-undercut method. In this system access tunnels and haulages are developed from the shaft to the contact of the ore bodies. The draw horizon is then developed complete with draw points. The block is then brought into production by advancing the undercut front (cave line) over the draw horizon. The undercutting can be done from a separate level above the draw horizon or from the draw points.

Block cave development using an advanced undercut system. In this system the country rock development is advanced to the ore body and the undercut front is advanced before the draw horizon has been developed. The draw horizon and draw points are then developed in destressed conditions. The use of this system normally requires the development of a separate undercut level. The advanced undercut system should not be confused with a pre-undercut system in which a large extent

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of undercutting may be carried out before development of the draw horizon. This is definitely not recommended for deep level block caves.

Threats to the stability of the draw horizon

In the design of a block cave the mining engineer must have a sound knowledge of the factors which affect the draw horizon stability. These factors are listed here.

General stress-induced damage

The increase in stress associated with undercutting is considered to be the major factor that affects the stability of the draw horizon. The effect of this stress change is to increase the fracturing of the rock mass surrounding the undercut level. The situation is made worse if a post-undercut method is used. In this case the undercut abutment stresses are concentrated in the pillars between the drifts and

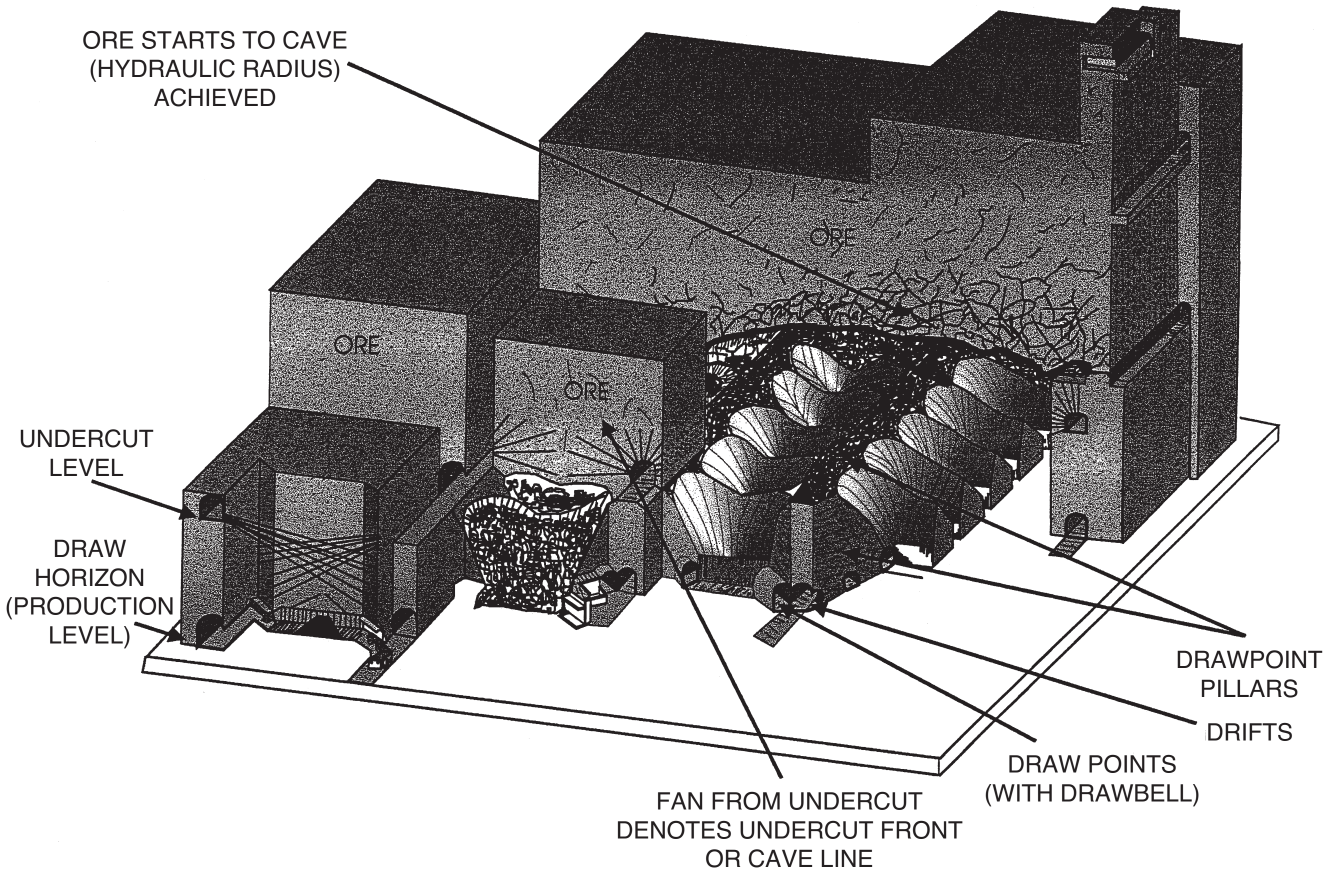

Figure 1—Trackless block cave layout (Brumleve and Maier, 1981)

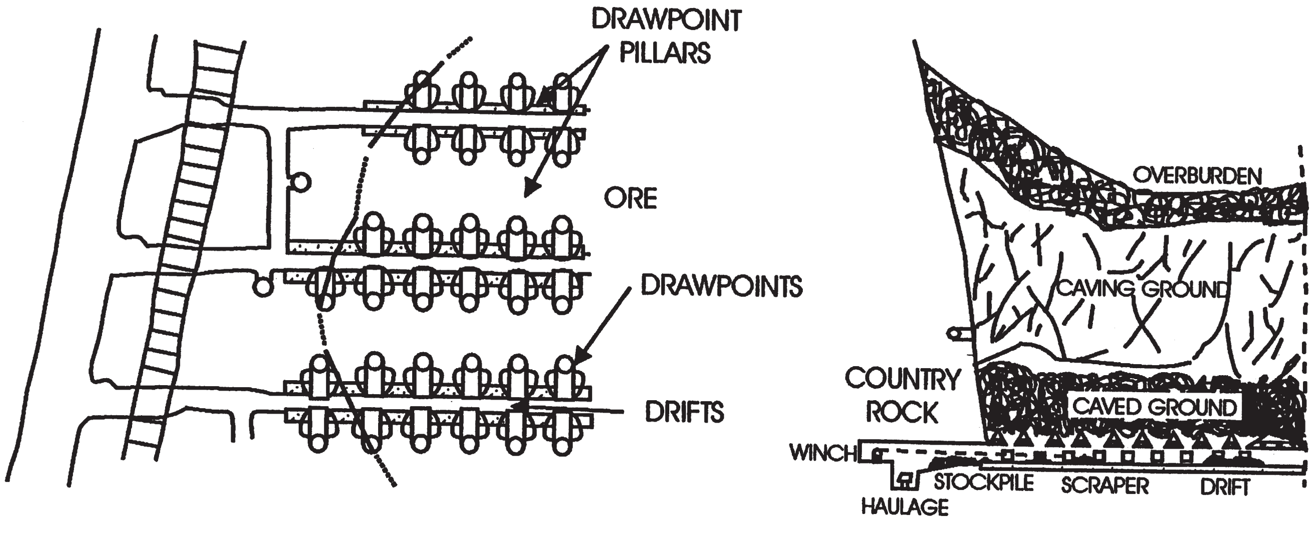

Figure 2—Slusher block cave layout (W.K. Hartley, 1981)

draw points, resulting in possible scaling and failure of the pillars and drift damage. The drifts can be further damaged by the relaxation of the fractured rockmass which occurs after undercutting. The magnitude of this damage is normally proportional to the depth below surface, the undercut height, the distance between the undercut and the draw horizon, the strength of the rock mass, and the pillar size. It has been found that where draw horizon development accounts for more than 60% of the level (i.e. only 40% of the area is left as pillars) stress-induced damage becomes unmanageable. In the case where in excess of 80% of the draw horizon is developed such as in the case of a slusher block cave, the post-undercutting induced stresses can result in severe damage and the collapse of this level. It is questionable whether the post-undercut method is suitable for slusher block cave development below depths of 500 metres. It should be noted that the magnitude of damage is increased if drawpoint and drift development is left unsupported for a considerable period. Under such conditions the collapse of the draw horizon may occur during undercutting.

Stress concentration due to large irregularities in the horizontal configuration of the undercut front (cave line)

Large irregularities in the horizontal configuration of the undercut front (cave line) cause an increase in stress concentration, which may result in serious damage. An illustration of this concept is given in Figure 3. The lagging zone will be subjected to significantly increased stresses.

Stress-induced damage due to slow undercut rates of advance

The speed of the undercut is an important factor in the magnitude of stress-induced damage to the draw horizon. Stress-induced damage increases with a reduction in the rate of advance of the undercut front (cave line). The undercut abutment stresses reach the maximum magnitude when the undercut area equates to the required hydraulic radius of the block. It should be noted that stress-induced damage starts to increase once the undercut area equates to half the required hydraulic radius of the block. The concept of determining cavability by using the mining rock mass rating system and the hydraulic radius (Laubscher, 1994) is given in Figure 4.

Undercut front arch-induced crushing due to the non-propagation of the cave

As the undercut starts to advance an arch is formed above this area. The span of the arch increases until caving is achieved at hydraulic radius. At this point caving of the ore body will naturally continue to propagate if drawing commences. As drawing commences there is a reduction in undercut front stresses. However, if an area equating to hydraulic radius has been undercut but drawing does not commence and the undercut continues to advance, the undercut front stresses increase with increases in the span of the arch until crushing of the undercut front occurs. From the author's experience with caves in diamond mines, this normally occurs when the undercut advances about 45 metres linearly across the block from hydraulic radius position.

Design rules

Taking cognisance of the listed threats the following are empirical design rules which, when implemented, can reduce or eliminate damage to the draw horizon.

Rule No. 1: Block cave advanced undercutting

Considering the fact that post undercutting results in the stress-induced damage to the draw horizon level it would be prudent that the undercut should be advanced first and the draw horizon should be developed in de-stressed conditions. *Therefor, the first rule of draw horizon damage reduction is that advanced undercutting of the block cave should take place*. However, the use of advanced undercutting has the following disadvantages:

- Increased capital cost due to the fact that an additional level is required
- Sequence problems because draw horizon development must follow closely behind the undercut to avoid the regeneration of undercut stresses due to undercut muck pile compaction. In the author's experience the time lag between undercutting and draw horizon development should not exceed 6 months.

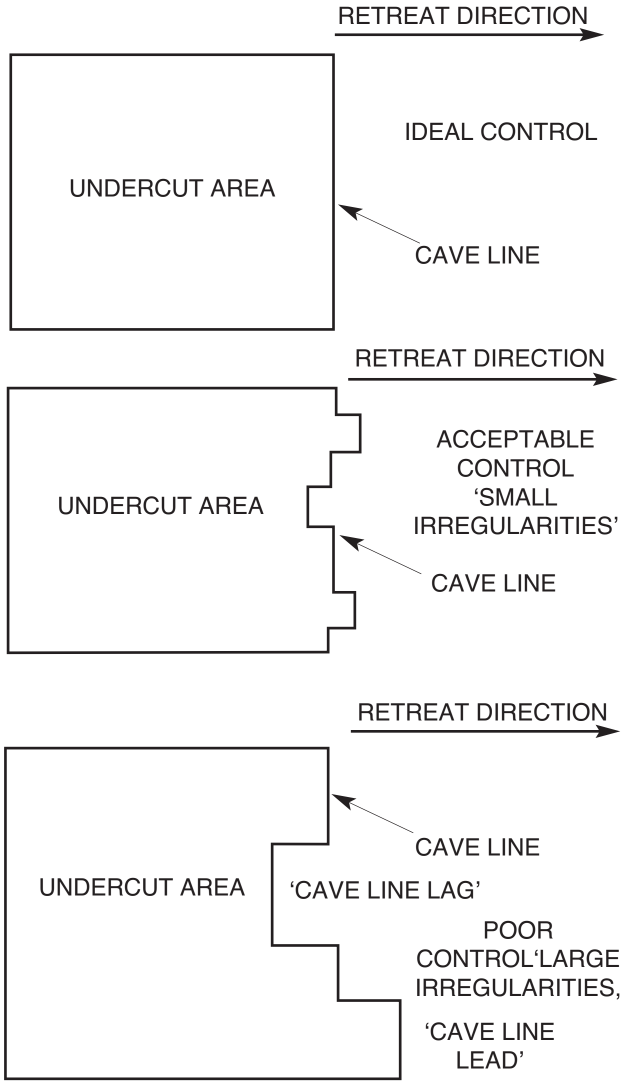

Figure 3—Cave line geometries in plan

- The additional time taken to bring the block cave into production due to the delay between undercutting and draw horizon development.

In certain circumstances, it may not be possible to use advanced undercutting. Under such conditions, such as block caves with dimensions equating to the hydraulic radius, the percentage extracted for drift and draw point development on the draw horizon must be kept as small as possible. It is the author's experience that for moderate draw horizon damage, drift and draw point development must not exceed 40% of the plan area of the draw horizon, before undercutting.

Rule No. 2 : Control of the horizontal configuration of the undercut front (cave line)

Large irregularities in the horizontal geometry of the (cave line) undercut front cause an increase in stress concentrations resulting in serious damage. *Therefore, the second rule of damage reduction is that the horizontal irregularities in undercut front geometry should be kept to a minimum.* The irregularities can be thought of in terms of undercut front panel lag distances. Based on current knowledge the suggested guideline limits for undercut lags are given in Table I. These limits are applicable up to a depth of 1300m and for rock masses with MRMR's in the 25 to 50 range.

Rule No. 3: Undercut advance rates

As mentioned previously, the damage to the draw horizon is related to the rate of undercut advance, and in this regard *the rate of undercutting (RU) must be greater than the rate of damage (RD) to the draw horizon.*

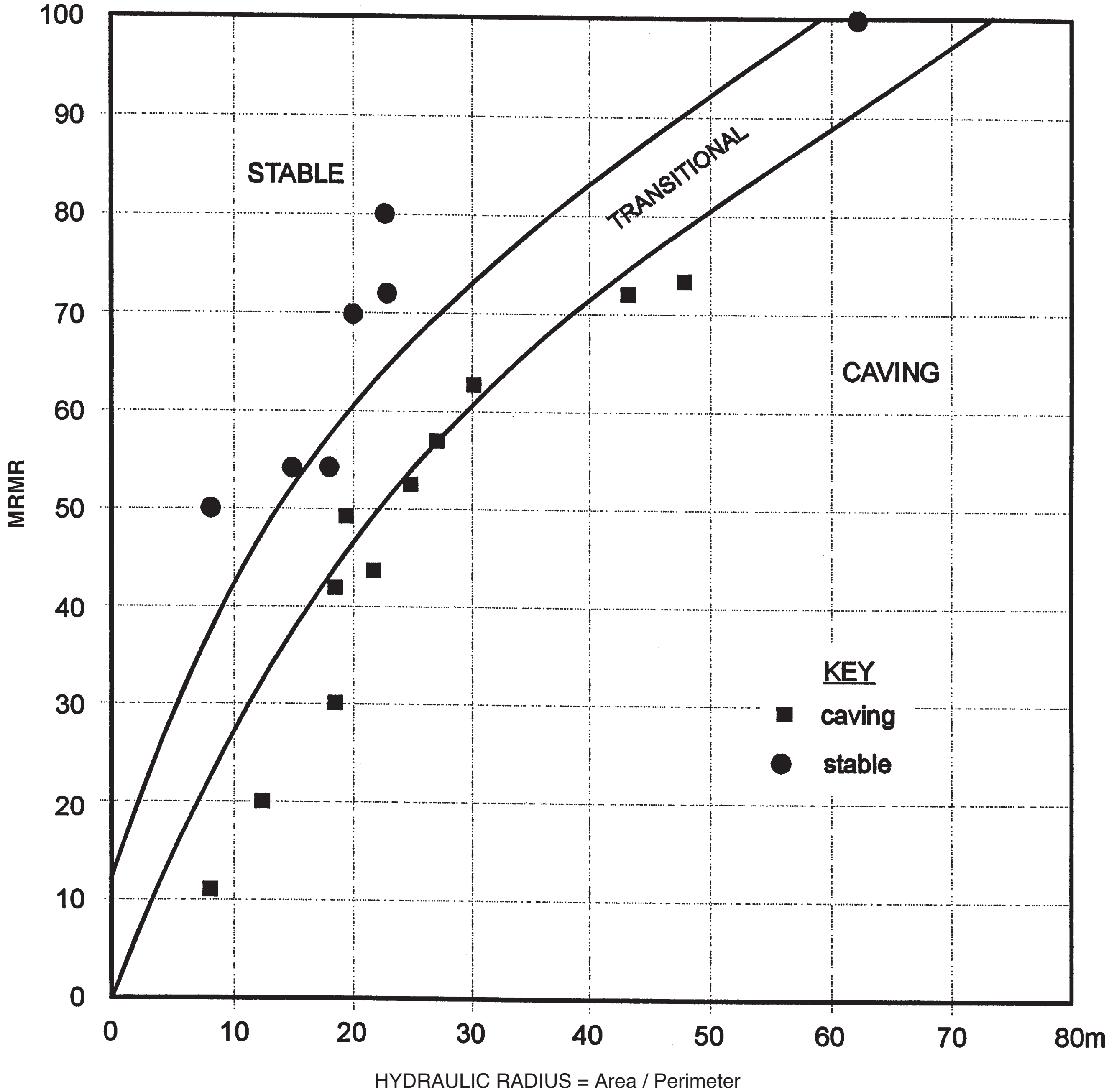

Figure 4—A stability diagram for various mines worldwide (After Laubscher 1994)

Table I

Undercut face lags and corresponding stress conditions and damage

(Cave line) undercut front lag distance	(Cave line) undercut front stress conditions	Damage
<5m	ideal	minimum
8m	moderate	moderate
10-12m	high stresses	severe
12m +	very high	(cave line) undercut front crushing

RU > RD

However, after the block cave has been undercut to an area equivalent to its required hydraulic radius, it is important that the rate of undercutting is never greater than the rate of caving (RC). This is in order to prevent the formation of an arch above the undercut face which could lead to undercut front (caveline) crushing, which in turn could allow the propagation of the cave to occur. In this regard the following rule should apply after the block cave's hydraulic radius has been achieved (Laubscher, 1994).

RC > RU > RD

It is the author's experience that undercut advance rates in the region of 1100m^2 per month are sufficient to prevent severe damage. It should be noted that these advance rates were obtained from experience with post undercut slusher cave at depths in excess of 500 metres. As a general rule the smaller the undercut height the faster the undercut rate, due to the fact that less drilling and charging is required than for the larger undercuts. The undercut height should be as small as possible, and it is the author's experience that undercut heights of 1.5m can suffice. However, in practice, minimum undercut heights tend to be in the region of the height of the undercut development.

Rule No. 4: Elevation of the undercut

The height of the undercut above the base of the draw horizon varies from mine to mine. However, since the damage effects from undercut front (cave line) stresses decrease with an increase in vertical distance between the draw and undercut horizons, *the fourth rule of damage reduction should be that the undercut horizon should be placed as high as practically possible above the draw horizon*. It is the author's experience that the most practical distance between the undercut and draw horizon levels, in terms of draw control, stress and induced damage reduction, and hang up access, is in the region of 15 metres.

Rule No. 5 : Cave propagation to eliminate undercut front arch-induced crushing

A further consideration in reducing the magnitude of undercut stresses is to ensure that the undercut reaches the hydraulic radius position as quickly as possible. This is necessary to ensure that cave propagation can occur with the effect of reducing the magnitude of undercut abutment stresses. Since caving is affected not only by the undercut dimensions but also by the rock mass strength, *the fifth rule of block caving is that the undercut front must advance from the weakest ground to the strongest ground thus ensuring that cave propagation occurs as quickly as possible*. An additional benefit of the application of this rule is that final portions of the block to be undercut are always situated in the strongest ground, thus reducing the magnitude of stress-induced damage further.

The above rules have been determined by experience gained on deep level block caves. It is believed that the application of these empirical design rules will provide the basis for avoiding stress-induced damage to deep level block caves, thus ensuring that planned block caves achieve their full production potential.

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Demand for niobium reaches record levels

New report analyses supply and demand worldwide

Demand for niobium has increased over the last decade, rising from an average of just over 19,000 between 1990 and 1993, to reach a record level of 28, 740 t in 1997, according to a new report from market analyst Roskill. The Economics of Niobium (Eight edition) says that despite this sharp increase, prices have remained stable due to the efforts of the three leading niobium producers (CBMM and Catalão of Brazil and Niobec of Canada) to match output to demand.

New projects boost supply

The strength of these three companies has largely obviated the need to develop new sources of niobium, despite strong growth in demand over the past two years. As a result, no significant new sources of niobium production have, as yet, appeared. However, Roskill says that this situation may possibly change in the future. A number of attractive deposits ar under investigation, and feasibility studies are being undertaken at sites around the world. Paranapanema of Brazil plans to establish a plant to produce up to 4,000 t lpy of niobium products, including oxides and alloys. Niocan of Canada plans a project to produce up to 4,540 tlpy of ferro-niobium, while Reunion Mining of the UK have entered into an agreement with Treibacher Industrie of Austria and NMC of the Netherlands, to develop the Mabounié deposit in the Gabon. FeNb capacity is to be 6,000 tlpy.

Effects of recession?

Shipments of niobium oxide rose by 75% from 1996 to total 2,731 t in 1997. Roskill says that this dramatic increase was due to increased demand in superalloys for use in commercial aircraft, stationary has turbines and corrosion-resistant applications.

However, the report points out that the market for niobium in superalloys is very cyclical. The consequences for the aerospace industry of the financial crisis in Asia are, as yet, difficult to assess. A downturn in superalloy consumption, and therefore in niobium demand, is unlikely to be seen for some time. Manufacturers have large order backlogs, and any cancelled orders are being directed to other customers. Therefore, if the economic downturn spreads no further than Asia, the CIS and Latin America, the effects on niobium demand will be small.

However, if growth slows in most industrialized countries, it is likely that world-wide shipments of niobium will decrease. Demand for niobium, expected to total over 29,000 t in 1998, may decline by as much as 10% by 2000. The longer term prospects for niobium look good, and Roskill expects demand to resume its recent strong growth after the turn of the century

HSLA steels account for nearly three-quarters of all ferro-niobium consumption by the steel industry. Demand from this market has been driven by the strong in HSLA steel usage in automobiles, a trend largely resulting from the need for automobile companies to reduce the weight of their vehicles in order to meet government-imposed fuel consumption and emission level requirements. In the USA, the average consumption of HSLa steels has more than doubled, form 60 kg in 1978 to 134 kg in 1998.

Approximately 500 tlpy of high-purity niobium pentoxide is used worldwide, mainly in the production of capacitors, lithium niobate and optical glass. Of this total, Japan accounts for around 60% and the rest of the world 40%.

The Economics of Niobium (eight edition, 1998) is available at £700/US$1400 from Roskill Information Services Ltd, 2 Clapham Road, London SW9 0JA, England. Tel: +44 1717582 5155, Fax: +44 171 793 0008. Website: http://www.roskill.co.uk. ◆

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