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HIGH-INTENSITY AUTOGENOUS CRUSHING

Developments in the Barmac vertical-shaft impactor design

by Bryan A. Bartley

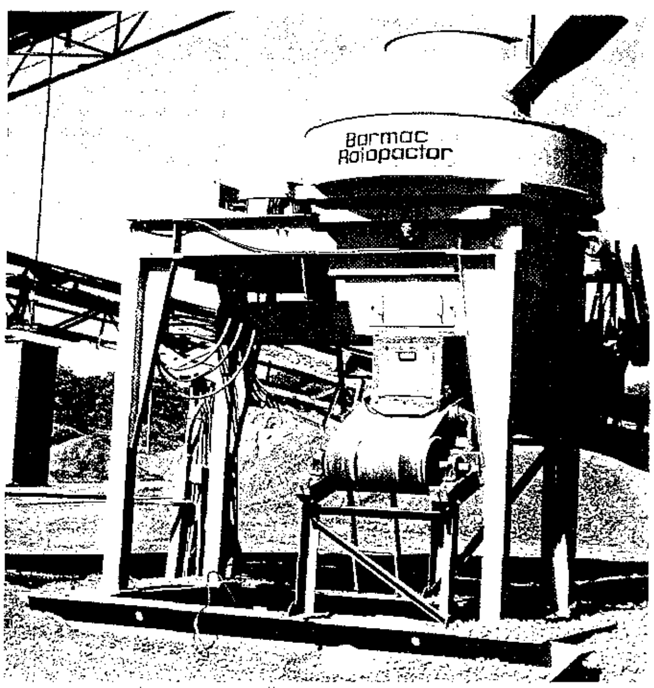

FIG 1 A typical Barmac installation for aggregate processing

From the beginning of the mechanization of rock breaking, men have thought of hitting rock against rock, now known as autogenous crushing. From the 1920s and 1930s there are patents for machines that demonstrate this effort, but the only practical survivors are cascade mills in which the charge of stone is rumbled in a rotating drum, causing the stones to break down. A variation on this is the pebble mill in which big pebbles of hard rock crush a softer material, much as steel balls do in a ball mill. A semi-autogenous mill (SAG mill) is a cascade mill to which steel balls have been added to improve the action; these machines use a low velocity of impact (up to about 14m/s) and so can be classified as low-intensity autogenous machines.

The practical means of using high-intensity, autogenous crushing and grinding (70m/s) was invented by a New Zealand engineer, Jim Macdonald, for use in a hard rock quarry. The machine was patented and successfully developed in the quarrying industry, to the point where there are now over 900 in commercial operation around the world and their application to mineral processing purposes is being recognized.

THE AUTOGENOUS VERTICAL-SHAFT IMPACTOR

The autogenous, vertical-shaft impactor is illustrated in figs 1–4. The crushing chamber is lined by a bed of ore trapped above a shelf and the unique feature is the practical lining of the rotor, so that the accelerating surfaces are also of trapped stone. The outside edge of this material in the rotor is held in place by tips of tungsten carbide; thus, all the wear in accelerating and impacting the stone is on stone with the exception of the tungsten carbide edges which are very practical in resisting the rubbing wear. The tips are placed to avoid impact from particles outside the rotor.

This impactor represented a technical breakthrough in quarry applications, producing a machine with low capital cost, very low wear cost and capable of giving a remarkably good particle shape.

The autogenous machine is not to be confused with the vertical-shaft impactor which has hammer blocks on a spinning table and breaker-bars around the crushing chamber. This configuration is very similar in action to a hammer mill with a high cost of wear and a need to drop the broken material quickly from the breaking chamber to allow further impacts against the breaker-bars.

Action within the rotor

There is a very high level of acceleration within the spinning rotor. Consider a particle entering the centre of the rotor. It has little or no radial velocity. With the flow of air and other stones it moves radially outwards until it comes in contact with the trapped stone forming arms within the rotor (see fig 3).

This trapped stone surface is at the angle of repose of the stone in relation to the centripital acceleration which acts radially. The angle of repose of a stockpile is approximately 35° to the horizontal or 55° to the acceleration of gravity, which is vertical. In the same way, the characteristic shape of the build-up in the rotor is a spiral at 55° to the radius.

The particle considered above meets this rotating arm of trapped stone. From negligible velocity, the particle is accelerated down the repose slope to emerge at a velocity of 75ft/s at an angle of 28° to the tangent, both measured in relation to the crushing chamber. Calculations indicate that the acceleration averages over 650 times that of gravity and may act for about 11ms. This constitutes a severe blow.

One interesting question is: 'Do the particles roll, or slide along this accelerating surface?'. Stone-on-stone friction is likely to be high and under this high acceleration one would expect the rounded, or more cubical, particles to roll. If there is no slip, a 20mm particle would reach the improbable rotation of 1,000rev/s. Hence, a combination of spinning and sliding is most likely. This spin adds another aspect to the high-intensity impacts. Does the spin transfer to the impacted particle and further test its strength?

A flat particle would probably slide but, with the high acceleration, must be subject to very severe rubbing wear.

Action in the crushing chamber

High-speed particles come flying out of each port in the rotor, so that a stationary point in the breaking chamber would see three squirts of stone per revolution of the rotor. At 1,500rev/min this represents 75 squirts per second or one every 13ms.

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The thrown particles are almost tangential to the rotor and, together with the air from the rotor (acting as a large fan), become part of a powerful forced cyclone, or a swirling mass of particles.

The stationary bed of particles in the breaking chamber is not an anvil surface, but a conical, wear-resistant chamber lining that provides an uplift component as the swirling mass continually changes direction.

The breaking action can best be visualized as impact between billiard balls in mid-air:

(a) A fast direct hit can cause breaking and the broken particles can have new speeds — some faster and some slower than the original larger, unbroken particle

(b) A glancing blow transfers the energy between particles and can be a fierce rubbing or grinding, right down the energy scale to a gentle rubbing or polishing

To continue the billiard ball analogy, breaking a set pattern of balls, as in snooker, demonstrates in two dimensions how energy is transferred. Particles are subject to an impact force. They either break, and in so doing take up energy, or they are tested for strength and if strong enough, pass on the energy elastically to the next particle.

The set of sieve analyses in fig. 6 demonstrates a very interesting phenomenon. As the flow rate through the rotor and breaking chamber increases, the product gets finer. This implies that, as the population density of particles in the breaking chamber increases, the energy is used more efficiently. This effect is further considered later in this paper.

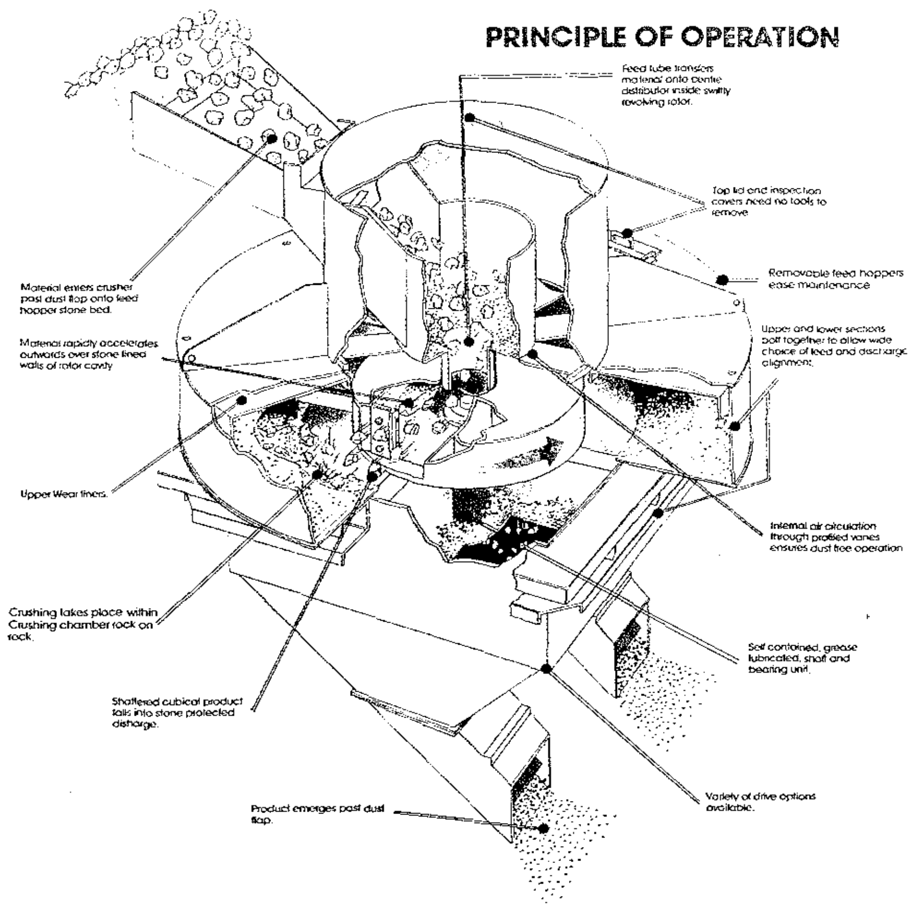


FIG. 2 Sectional view of the autogenous, vertical-shaft impactor

FIG. 3 Rock build-up within the rotor eliminates high wear costs

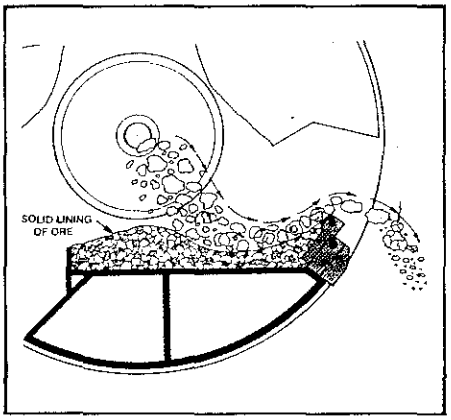
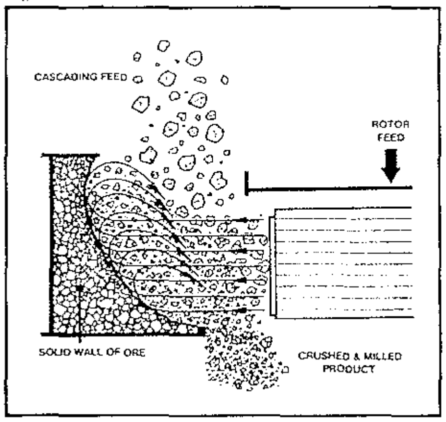


FIG. 4 The same effect is achieved within the crushing chamber



Levels of impact

The best known forms of autogenous grinding are the cascade mill and pebble mill. These are limited in the speed of impact they can achieve by the critical speed of rotation, so increase in impact requires an increase in diameter. A 6.5m diameter mill has a maximum impact velocity of about 11m/s. This level is suitable for easily broken material having special properties so that sufficient large material survives to provide adequate breakage of the finer material. Impact energy is proportional to mass times velocity squared (mV^2), with V fixed by the size of the machine, an increase in impact energy can be achieved by increasing particle mass; hence the addition of steel balls for the SAG mill to gain more impact.

Hammer mills operate at about 30m/s. Above this level, in abrasive stone, the wear cost becomes excessive and exotic alloy steels are used to raise the wear life and, if possible, hold down the cost of wear.

The high-intensity autogenous impactor such as the Barmac Rotopactor operates at about 70m/s. This is an energy intensity five times that of a typical hammer mill and about 50 times that of a large cascade mill.

THE DUOPACTOR PRINCIPLE

A further inventive step has been to add a second flow of feed material into the top of the breaking chamber. The cyclone action and swirling mass of flying particles lift up into the top of the breaking chamber. As particles fall, they are again impacted by the high-energy particles from the rotor at 75 waves per second, and again swept up in the action. A second flow of feed material added into the top of the chamber is immediately swept up in the same way and subjected to impact and grinding until eventually it escapes with the other particles.

If we have a machine operating as a Rotopactor with the rotor fully loaded (ie drawing full motor power) we will get a certain production rate. Consider the product required is 7mm from a closed circuit on a screen. If the machine is now converted to a Duopactor and a second flow of feed, equal to that through the rotor, is added to the top of the breaking chamber, then the production of 7mm will increase by about 35%. If the cascade flow is twice that through the rotor, then the increase in 7mm product is approximately 60%.

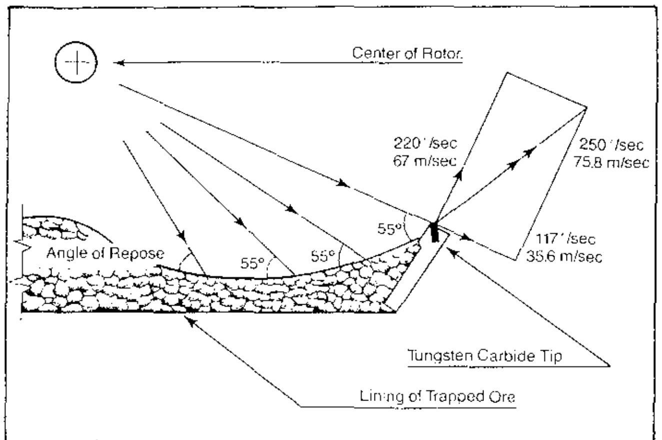


FIG. 5 The rotor geometry

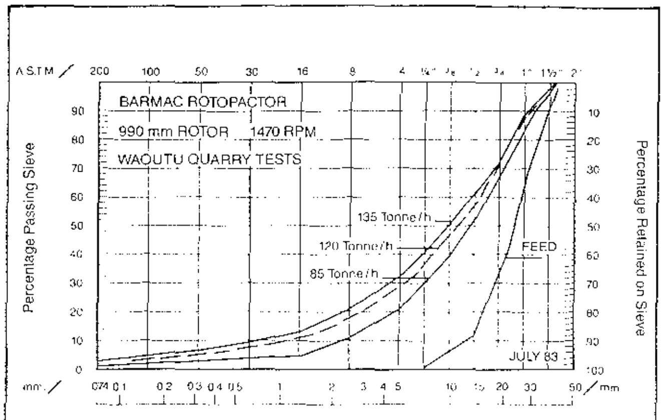


FIG. 6 Sieve analysis

The important point to note is that these increases in production are achieved for no extra power consumption or wear cost in the crusher. The screen and closed circuit will be handling an extra two or three times the original quantity, but screening costs are usually very low compared with the power, wear cost and capital cost of crushing. The increase in performance is more significant at higher tip speeds, ie at higher energy levels.

The Duopactor comes in two forms. First, the second feed is of the same size as the rotor feed. In this arrangement the feed to the machine increases to fill the rotor to full motor power, then further increases overflow and cascade into the top of the breaking chamber. This is the cascade Duopactor.

In the other option, the second feed is larger than that through the rotor. This requires two entry points, and two separate feeds (see fig. 7). This is the dual-feed Duopactor.

One feed is to the rotor with an acceptable top size of about 50mm; the second can be larger, say 100mm. In easily broken material the big particles will be reduced and may come through the rotor on the second pass. In hard rock the big particles will survive and recirculate. Weak ones may break, but the strong will be worn away and serve the function of mobile anvils, against which smaller fast particles can break. This oversize might build up in volume if the rate of supply is greater than the rate of reduction; this may require a return to the previous crusher or to a separate minor crusher.

The features of the cascade and dual-feed machines include:

1. The second feed can provide mobile anvils for the fast particles, as above
2. The second flow is added at the top of the cyclone, swirling mass of particles. It is almost stationary as the first particles interact, so improving the velocity difference between fast and slow particles
3. The benefit continues at higher cascade flows such as three times the rotor flow, but with a diminishing rate of return (see fig. 6)
4. The second flow increases the population density in the breaking chamber and the energy provided is used more effectively in breaking more particles. This implies that energy is best used between particles, and therefore energy absorbed in the stationary bed in the breaking chamber may be considered as energy wasted. This is in strong contrast to the concept that the bed could be an anvil surface or that break-bars are necessary or desirable
5. As the cascade flow increases, the total product from the machine becomes coarser, even though the tonnage of fine material increases. The cascade ratio thus provides a further means of grading control for specification products.

BOND'S THEORY

Bond's theories of comminution are often used to evaluate the energy efficiency of crushing and grinding machinery. Anyone interested in this topic should refer to a paper presented to the SME conference of the AIME in Phoenix, Arizona, in January, entitled 'Efficiency of Barmac crushers by modified Bond method', and presented by Dr Kelly. Results indicated Bond efficiencies for the Rotopactor ranging from 37% to 86% and for the Duopactor ranging from 57% to 117%.

ABRASION RESISTANCE

The silica content of materials is normally considered when choosing crushing equipment. Most machines are economic up to certain silica contents; above this the cost of wear becomes prohibitive. The autogenous machine is much less affected by this wear cost and has found application in crushing quartz for releasing gold.

An early application in England was for the reduction of tin slag and copper slag for use as sand-blasting abrasive. Wear cost, averaged over the whole year, was reduced from 120p per tonne, for a hammer mill, to 2p per tonne for the autogenous vertical-shaft impactor.

This was followed by crushing in England of corundum (sintered Chinese bauxite) and in America, carborundum. The previous method of crushing the bauxite with a hammer mill required the hammers to be turned after 4½min and replaced after 9min. The corresponding tip life in the vertical spindle autogenous rotor is 4h. The saving in cost of wear-parts is dramatic, but more important factors are the savings in maintenance labour cost and machine availability.

PARTICLE SHAPE

In New Zealand the particle shape for road-sealing chippings is specified in terms of 'average greatest dimension' divided by 'average least dimension', and is required to be better than 2.25. A sphere has a ratio of 1, but a perfect cube has a ratio of 1.73. Rotopactor chippings in hard rock commonly achieve 1.9 and are considered to be very cubical.

This shape characteristic is also important in concrete aggregate where the reduced water demand associated with good workability is reflected in a saving of cement and ease of pumping.

TRAMP METAL

For most rock-crushing machines elaborate means are provided to relieve the excessive forces generated by tramp metal. In the high-intensity autogenous machine, the rotor is protected, since all feed is screened to about 40mm and the rotor discharge opening is approximately 200mm x 150mm. Thus bridging and blocking is not a problem.

The machines are used for reducing blast-furnace slag where tramp metal, in the form of blobs of steel in the slag, is a normal feed material.

OTHER CHARACTERISTICS

As well as the abrasion resistance and particle-shape characteristics considered above, there are three other characteristics that should be noted. These are:

1. *Preferential crushing* — Hard particles survive the crushing and grinding better than soft particles. This has provided an economic upgrading and separation of hard particles from soft
2. *Grinding* — Autogenous grinding becomes economic with the

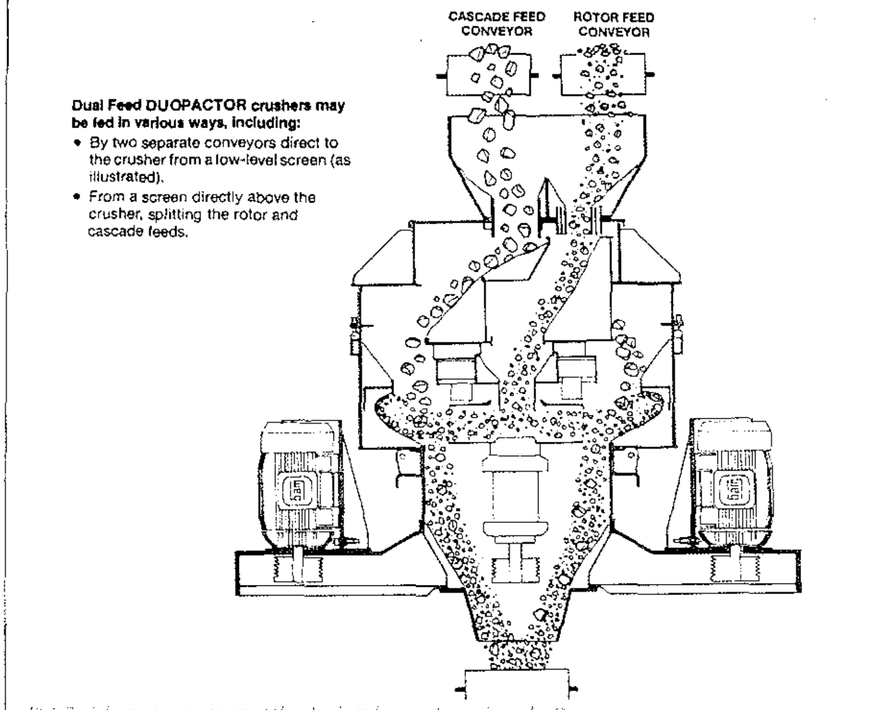


FIG 7 Schematic diagram of the dual and cascade feeds in the Duopactor

high-intensity and relatively cheap machine. Manufactured sand is a product of this process.

3 *Drying* — The energy of attrition grinding and rubbing raises the temperature of the stone and air, while the fast air flow assists evaporation. The surface area produced by the crushing and grinding also absorbs moisture.

An abrasive limestone in Scotland has produced a very interesting application. It has been a traditional practice for this limestone to be dried with an oil-fired dryer before crushing. The autogenous machine produced sufficient drying effect to save the drying cost. In one plant in Scotland two Rotopactors replaced five roller mills and two dryers. They now produce 54 tonnes/h of [illegible] of which 35–40% passes 150 microns.

This Scottish limestone has an SiO_2 content of 22–28% so a hammer mill previously used required a hammer turn after one-and-a-half days and removal for rebuild after three days. In this application the autogenous machine saved on wearparts as well as £1 per tonne for drying.

POWER RANGE

For a given tip velocity (impact level) the rotor throughput is directly proportional to the horsepower, for example, at a tip speed of 70m/s the power demand is 1.7kWh/tonne and for 58m/s the demand is 1.4kWh/tonne.

Machines are now available with the power range of 20kW to 370kW (25–500hp). A machine for 750kW (1,000hp) has been drawn up by Tidco, but not yet built. This looks to be a very practical machine, but is more likely to find use in mining than in quarrying.

For the Rotopactor, with all production passing through the rotor, the relationship between power and product is quite clear. The Duopactor has the complication that an additional flow, equal to that through the rotor (or possibly twice it) means that the output per kilowatt is doubled or trebled. Stated the other way round, the power per tonne is reduced, but to a lesser degree so is the benefit per tonne.

TABLE 1 Capital costs of the Duopactor

Barmac Duopactor	*Rotor throughput*	*Basic machine*	*Stand-alone unit with starter and largest motors*
Mk I	[illegible] tonnes/h	A$90 000	A$110 000
Mk II	[illegible] tonnes/h	A$145 000	A$[illegible]
Mk III	[illegible] tonnes/h	A$180 000	A$[illegible]

The high intensity of impact is still there, but is spread over more targets and used more efficiently.

PORTABLE PLANTS

The light weight of these machines, when compared with machines built of heavy castings, makes them particularly suitable for portable plants; this also shows in the foundations required. Many machines operate on skid mountings, while others are mounted in elevated positions in the steel frames of crushing plants. The nature of the action is such that massive concrete foundations are not required.

MACHINE COSTS

As a broad guide to capital cost, the 1988 figures given in table 1 may be of assistance to quarrymen not familiar with the machines. There is the standard machine developed in quarries and for quarrying applications. Recently extra-heavy-duty machines were introduced for the mining industry. These figures quoted are for the former.

The cost of wear is related to the silica content of the rock being processed. As a broad guide, the cost of wear is 4c/tonne, for dolomite crushed to −2mm, and 15c/tonne for a rock with 50% SiO_2. These costs include all rotor parts, the feed tube, all rebuilds such as touching up the hardfacing on the rotor and labour.

CONCLUSIONS

The autogenous vertical-shaft impactor provides a practical and economical alternative for crushing hard and abrasive materials.

The Duopactor principle provides a considerable increase in production for no extra energy or wear cost. It thus represents an increase in energy efficiency.

These machines have the following characteristics:

- abrasion resistance
- cubical particle shape
- can pass tramp metal
- preferential crushing of soft material over hard
- a drying capability
- a grinding capability, replacing some rod mills

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