THE DEVELOPMENT OF SAND MANUFACTURE FROM CRUSHED ROCK IN JAPAN, USING ADVANCED VSI TECHNOLOGY

TAKATO KAYA
Chief Engineer, Kotobuki Engineering and Manufacturing Co. Ltd., Kure City, Hiroshima, Japan

MAKOTO HASHIMOTO
General Manager, Overseas Project Office, Kotobuki Engineering and Manufacturing Co. Ltd.,

HUGO PETTINGELL ACSM FIQ

ABSTRACT

Over the last quarter century or more, the increasing demand for manufactured sand to replace declining natural resources in Japan has been tracked by a series of advances in sand-making techniques, using developments of the original Barmac Autogenous Vertical Shaft Impact Crusher technology.

The latest development, the V7 Dry Sand Making System, combines crushing with fines classification and grading control in a single automated package, resulting in designable sand with performance comparable to good natural products. Research is continuing into the optimal inclusion of microfines in manufactured sand to take advantage of the important contribution of hitherto waste material.

Keywords: manufactured sand; VSI, wet process, dry process, water-cooled slag, crusher dust, particle shape, fines control, workability, microfines.

Introduction

The invention in New Zealand of the Autogenous Vertical Shaft Impact Crusher in the early 1970's was originally driven by the need for well-shaped stone chippings for road surfacing. However, it was soon found that the crushed rock fines from these machines possessed some unusually advantageous properties when used as fine aggregate in concrete. The slightly rounded, equi-dimensional shape of particles throughout the size range led to better workability and strength compared to conventional crusher dust. In the years since then, much work has been done on analyzing the reasons for this superior performance, and in Japan, the use of VSI crushing has been steadily developed from its early simple shaping role to a now very sophisticated system for the production of consistent high quality sand from crushed rock. This paper will describe the steps *(Fig.1)* taken along the road by Kotobuki Engineering and Manufacturing Co. Ltd. (KEMCO), who started building VSI crushers as one of the original overseas licensees of Barmac[1] technology in 1978.

Early Application

The first machines were used almost exclusively to improve the shape of coarse aggregate, the rock on rock action being sufficient simply to break weak elongated and flaky particles across their shortest dimension, to remove projecting points by attrition, as well as smoothing off edges by a process of abrasion. By 1985, the application had been extended to include the reshaping of <2.5mm crusher dust, for which there was no market in Japan, allowing its use as a blending material in concrete and coated products.

The microfines problem

In Japan, the manufacture of sand is regulated by the appropriate Japanese Industrial Specification (JIS) of grading limits, which is somewhat akin to the corresponding ASTM. These limits, having been devised for natural sands, allow only limited amounts of material smaller than 75µm, and while in many countries specifications have been relaxed for crushed rock-derived sands, in Japan the limit is still quite strict. Traditional sand manufacture has therefore tended to concentrate on wet processes, using the classification techniques from natural sand processing to remove almost all material below 200#.

With declining supplies of natural sands, many rock quarries installed rod mills or other crushing equipment with wet fines removal systems to make fine aggregate for concrete: The problem with the resulting material is generally that particle shape could be improved, and there is usually a deficiency in the particle size distribution below 1mm that does not make for ideal concrete sand. Depending on the geology of the source rock, almost all crushing equipment displays this deficiency, and modern concrete sand requirements seem to recognize that an increase in the abundance of particles around 600μm is desirable. The autogenous VSI has the ability to improve both particle shape and, to a limited extent, grading; however it was necessary to modify the original design to allow feeding of wet sand at water content of 20% or so. KEMCO achieved this aim successfully in 1990, and this specialized version of the machine has been widely used in Japan ever since. *Fig.2* shows change in gradation at a typical installation. The improvement in particle shape is clear from *Fig.3*, and an increase in solids ratio of 1-2% resulting from this equates to a useful reduction in water demand. Since the additional microfines derived from this process come only from stone from which clay and other deleterious material has been removed, it is found advantageous to retain it, avoiding the need for further washing, and assisting with concrete workability and increasing strength.

At about the same time, the need was seen for a completely dry sand-making process, and KEMCO introduced a system that mated a VSI with a rotary air classifier to remove microfines from the shaped and graded <2.5mm crusher dust. This was the first stage in the ten-year development of an integrated dry sand manufacturing system.

Decline in natural sand supplies

Also in 1990, the Japanese government announced that a complete ban on dredged sand would be enforced after a ten year "slowing down" period. In around 1995, the 5-2.5mm (known as "No.7s") fraction of crushed rock fines, which had hitherto been a saleable product, ceased to be used and became available in large quantities as a source material for sand manufacture. In 2000, dredging of sand from the sea was indeed banned, and the considerable supplies of sand from mainland China were halted by order of the Chinese government in 2006, making Western Japan almost totally dependent on manufactured sand for concrete.

Sand from slag

In 2000 Kemco introduced another specialized version of the Barmac VSI, developed to crush water-cooled (and therefore wet and rather cohesive) blast-furnace slag from Japanese steelworks.

The V7 Dry Sand Manufacturing System

With the irreversible decline in natural sand resources, KEMCO saw the need for a process to turn crushed rock fines into sand that could be compared with the best natural products. Such a system should owe nothing to established practice, the aim being to produce material with equal performance but possibly very different characteristics to natural sand. Wet systems were considered unnecessary, environmentally difficult, wasteful of space (always at a premium in Japan) and expensive.

The first stage was to design a crushing machine for the V7, able to produce an abundance of the "difficult" sized grains discussed earlier from a feed of well below 10mm top size. This was achieved by developing existing autogenous VSI technology, but incorporating a milling function, using tungsten carbide impact members, and a restriction on the crushing chamber outlet, thus forcing the material into a zone of powerful attrition.

In a conventional autogenous VSI, the energy transfer necessary to break already small particles is difficult to attain, and merely increasing the speed, and thus the kinetic energy, of the particles has little effect beyond that of sandblasting extra filler into existence. This process does improve particle shape by breaking off or abrading protuberances, but for advantageous size reduction, impact of particles against some kind of relatively immovable object is necessary.

In the V7 crusher, when particles collide with the tungsten carbide hammers, effective breakage replaces mere abrasion, and the peripheral speed of the rotor can be somewhat reduced compared with fully autogenous machines. The design of the crushing chamber ensures that all particles are subject to multiple impacts before they can escape as product. The limitation on this process is the resistance to shattering of tungsten carbide: While this material has very high resistance to abrasion, heavy impact can cause it to break, so the feed size must be restricted to 10mm or less, depending upon the friability of the source rock.

The second important stage in the design was to devise equipment capable of selecting the desired product, while removing unwanted filler, and returning oversize particles and some overabundant coarser sizes for further reduction. The Air Screen was designed using a draught of air as a classification medium, allowing larger particles to fall first and to be recirculated, and successively finer material to drop further along the screen chamber. (*Fig.4).* Top size of the product is set by the aperture of the screen mesh, while an additional control, or damper, allows a proportion of the coarser particles to be diverted back to the crusher for further reduction, in order to control the grading of the product within close tolerances. This feature allows the US7 crusher to produce the necessary amount of 150µm-

1mm grains for an ideal particle size distribution. Fine filler is drawn off at the far end and is collected in a bag filter.

In its original form, this equipment, together with its transport systems, was sufficient to produce sand to the Japanese specification, since the latter forbids the inclusion of more than 7% minus 75µm in the sand, despite the fact that many end users have found advantage in rather higher filler content. Recently most plants supplied have included a “skimmer” after the air screen, to recover the coarser particles up to about 300µm that are otherwise lost to the bag filter. This addition has meant that sand size particles and larger sub-63µm can be returned to the product, improving the sand characteristics as well as increasing recovery.

General description and operation of the plant

The plant is constructed in the form of two adjacent towers, one carrying the crusher and air screen, fed by a bucket elevator, the other supporting the bag filter and skimmer assembly. The reason for this arrangement is to minimise the footprint, which is very compact, and to allow effective dust encapsulation to be achieved. Provided the plant is properly maintained, dust emission is as near zero as to be insignificant. *(Fig.5 Circuit diagram)*

Once set to produce the desired gradation, the circuit is electronically controlled by reference to the crusher power consumption, and signals to the damper and air screen blower control the recirculation and filler extraction respectively, allowing a constant gradation to be maintained.

The feed material of crusher dust, or other sub-10mm product, must be dry – around 2% water content can usually be expected direct from a crushing process. In some instances the added value may well justify drying, or even further crushing, being applied to low value waste products such as scalpings. Clearly the more filler in the feed material, the more will need to be disposed of after the process, but a rule of thumb is that the process will recover around 80% sand and 20% dry filler. It is usual to condition the finished sand with a small percentage of water, in a drum mixer placed at the end of the process, to prevent segregation and maintain consistency.

The process has been applied successfully to a range of rock types, including *andesite, basalt, diabase, granite, limestone, and sandstone,* and some have been used in recycling and slag applications. The most common application is to produce sand for ready-mixed concrete, but other products are possible, including building sands, playground sand, and so on.

The concrete sands have been found suitable as up to 100% replacement for natural sand, with cement savings possible in many cases. A bonus feature is the extreme reliability of the process in making a consistent product, allowing mix design to be controlled within narrow limits. Many operators of V7 plants have made radical modifications to their aggregate processing in order to accommodate increased demand for fine aggregate, and instead of crusher dust being considered a waste product; its production is now increased to keep up feed supplies for making sand.

Filler processing

While filler collected in the bag filter, derived from some rock types, can find a market, it must frequently be regarded as a waste product. In Japan, a process has been devised to turn the filler into a pelletised material that can be used as a road bed or soil strengthener where substrates have poor load bearing capacity – this involves adding about 3% cement in a specially designed batch mixer, and makes material that can be stockpiled rather than dumped. Such a process can be incorporated in the V7 plant as an optional extra.

Ongoing Research

KEMCO research into manufactured sand is currently concentrated on the use of more of the microfines. It seems to be the case that the 75µm (or 63µm in Europe and elsewhere) limit, which was presumably originally selected because common wet classification systems of the period were effective in cutting at that point, may be inappropriate for defining undesirable material in manufactured sand. Indications are that the size below which detrimental effects manifest themselves is rather smaller. KEMCO has researched this extensively and has concluded that above a certain particle size there is no harm in including microfines, and is developing suitable equipment to be incorporated into the V7 system, to reduce waste levels by retaining these larger particles.

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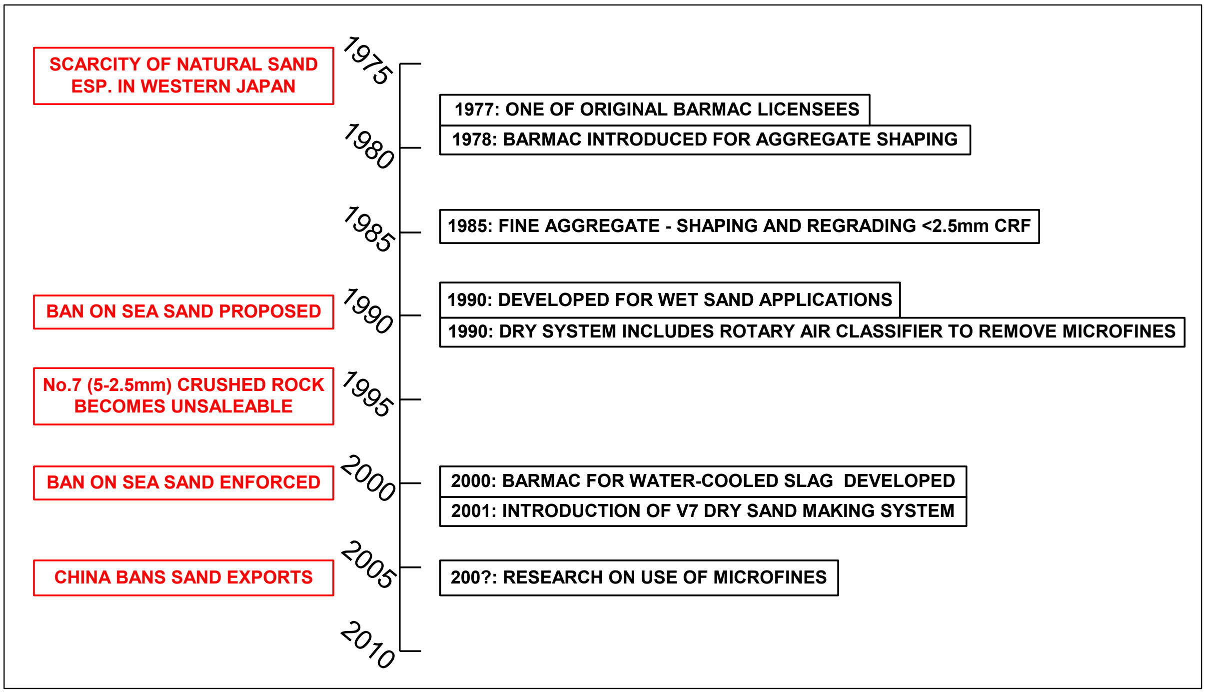

Fig. 1 The development of Kemco sand technology

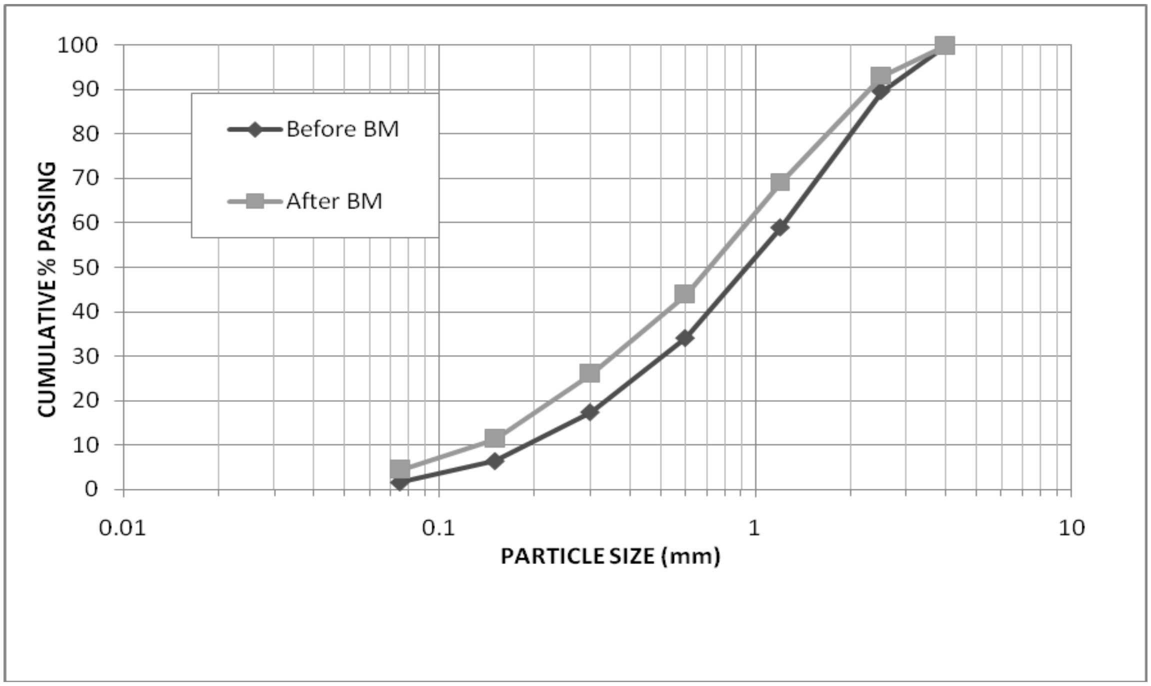

Fig. 2 Example of change in size distribution due to Kemco VSI, running with 20% water content.

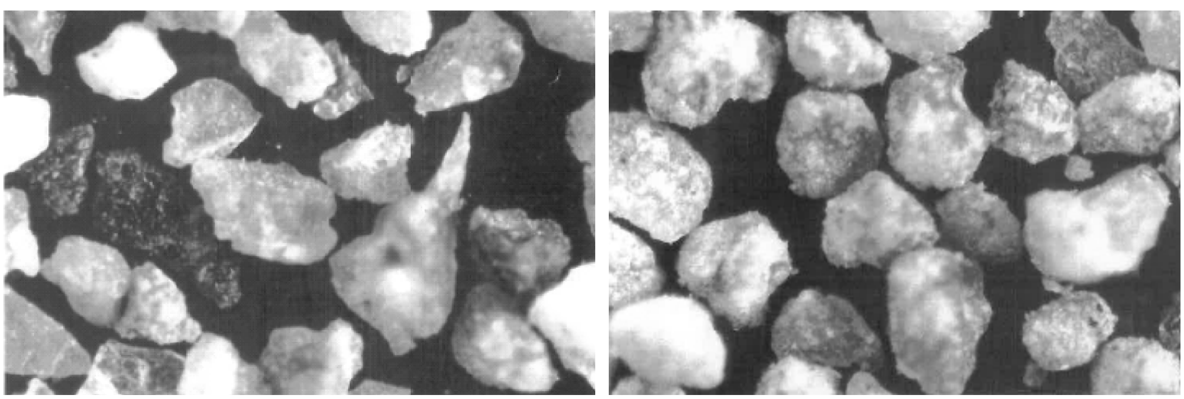

Fig. 3 Comparison of 2.5mm-1.5mm grains before and after VSI crusher.

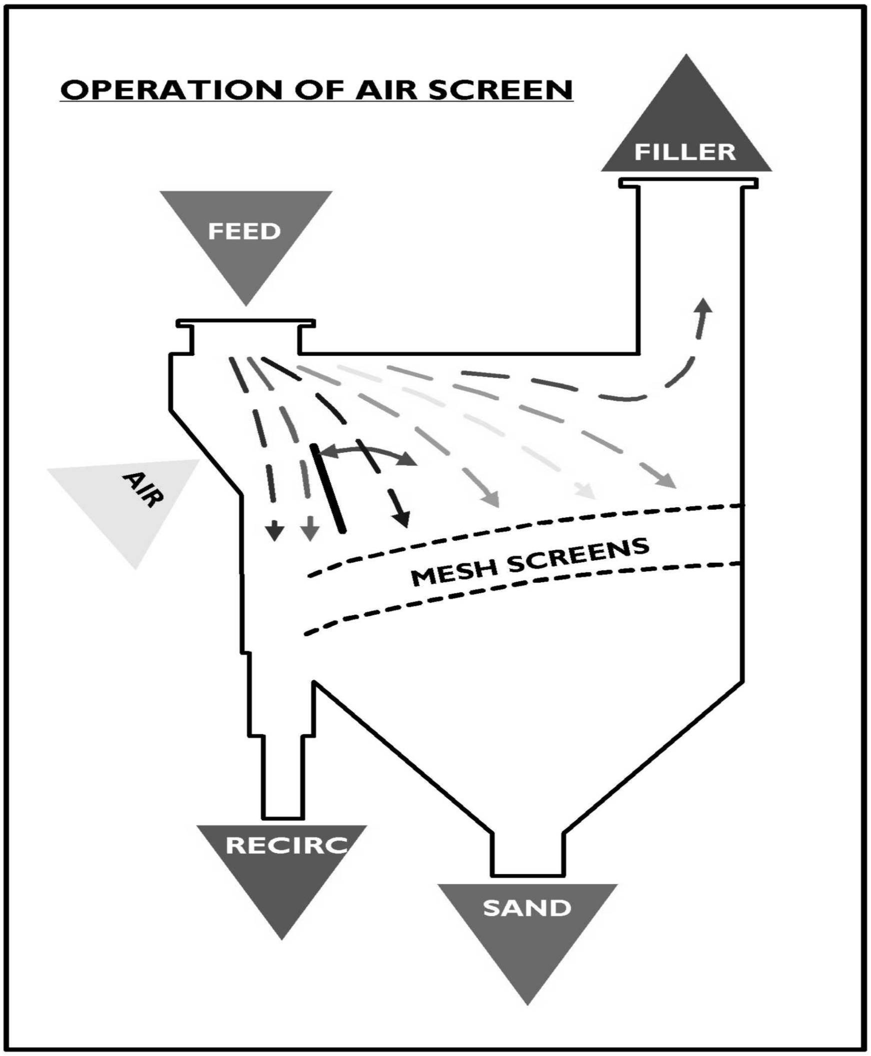

Fig. 4 Operation of air screen

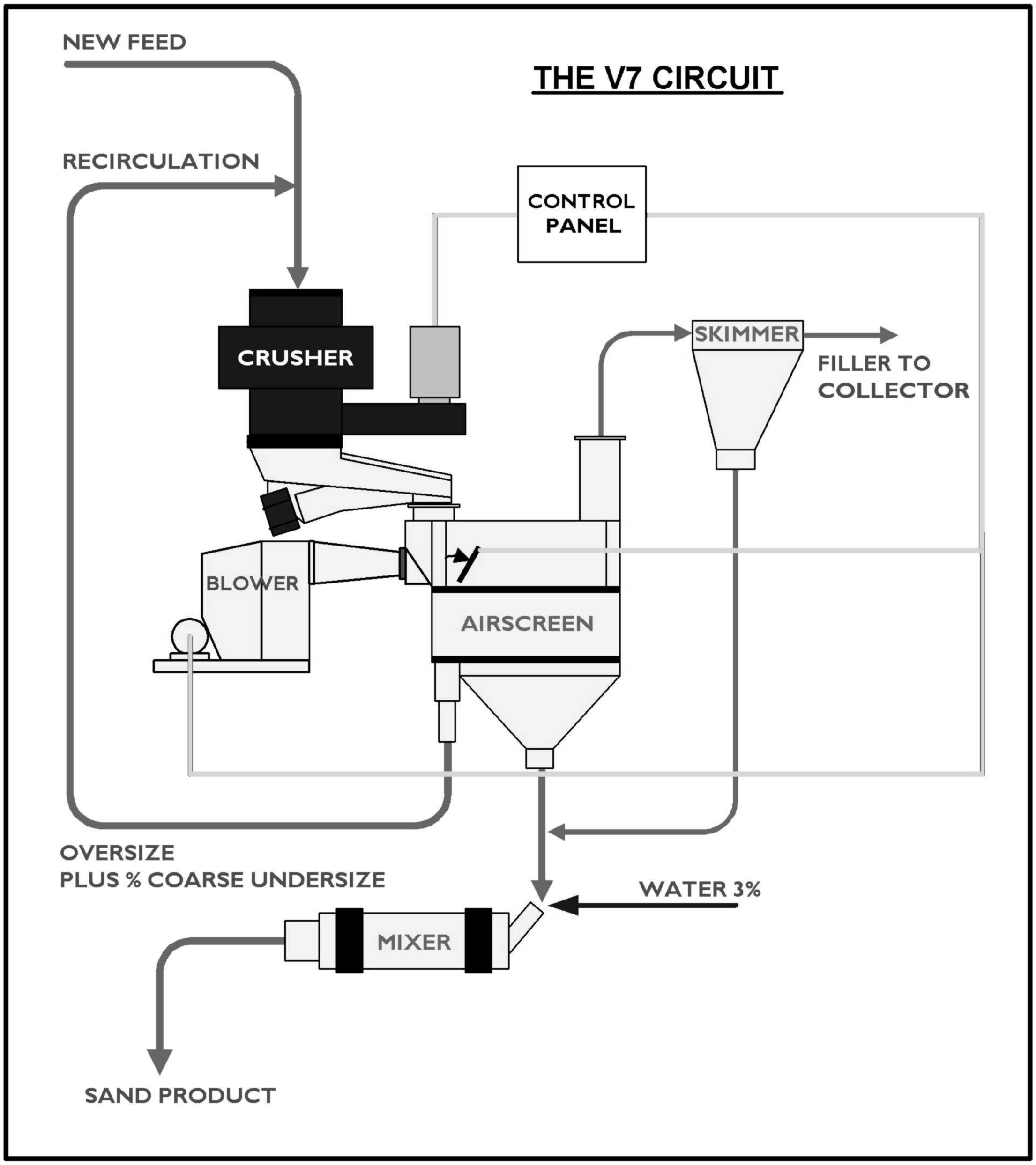

Fig. 5 V7 Circuit diagram