MINERALS FROM WASTE

Recent BGS & Tarmac experience in finding uses for mine & quarry waste

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ABSTRACT

In 1998 the BGS, in collaboration with Tarmac, initiated an industrial mineral waste project known as REFILL which was funded by the EU BriteEuRam programme. BGS was responsible for the characterization of quarry waste from certain aggregate quarrying operations across the UK. During the work it became clear that there was little information available on the quantity and technical quality of mineral waste in the UK. Also, BGS assisted Tarmac in research work to find uses for the fines produced at a coastal aggregate quarry in southern Ireland.

In 1999 BGS developed a further research project, known as 'Minerals from Waste', which was funded by the UK Government Department for International Development (DfID). This project aimed to improve the sustainability of mining communities by investigating the use of mineral waste as a source of construction and industrial minerals. The types of waste found in a range of extractive operations were reviewed. Case studies were carried out in Namibia and Costa Rica including investigations of the properties of the waste, mineral product evaluations, market and economic appraisals and social and environmental impact assessments of local communities. Overall, this work aimed to benefit not only mine and quarry engineers, but all those involved in the management of mine waste.

Keywords: Industrial minerals, Environmental, Waste processing

INTRODUCTION

Mineral waste can be defined as the 'residues, tailings or other non-valuable material produced after the extraction and processing of material to form mineral products' (Harrison *et al*, 2002). There is no universally recognized classification of mineral wastes. A classification scheme should take account of the economically important characteristics of the waste, especially its potential end use and the degree of processing needed. A simple scheme proposed by Harrison *et al* (2002) is shown in Table 1, with four descriptive categories:

Type 1 waste represents material that could be used with minimal processing, largely as construction material – the classic large volume, low value industrial mineral. The market would be within a short radius of the mine but large amounts of the waste would be removed.

Type 2 wastes would only require a small amount of processing to produce a mineral product, for example removing iron-bearing impurities from a quartz-rich waste to produce silica sand. Large amounts of waste would be removed with a small amount of secondary waste produced. The market would be largely local with the possibility of some national trade.

Type 3 wastes contain small amounts of a valuable mineral that would require a significant level of, potentially complex, processing to recover. The disadvantage to this is that a large volume of the mineral waste would remain and major capital investment would be needed for the processing plant. It is likely that the market for these high-value industrial mineral commodities would be international.

Type 4 mineral wastes contain very small quantities of a highly valuable target mineral (or more likely a metal content) with similar requirements and disadvantages to Type 3.

Group	Description	Example	Potential end uses
Type 1	Unprocessed wastes	quarry scalpings quarry blocks colliery spoil	fill, low grade road stone, armourstone, brick clay
Type 2	Processed wastes – reclaimed mineral	silica sand wastes limestone wastes building stone wastes	silica sand, kaolin, brick clay, mineral filler, aglime, aggregate
Type 3	Processed wastes – added-value products	lead/ zinc wastes pegmatite wastes silica sand wastes	fluorite, barite feldspar, rare earths, mica heavy minerals
Type 4	Beneficiated wastes	certain mine wastes	gemstones, high value metals

Table 1. Classification of minerals wastes

Research has largely focused on the recovery of the residual metal content of mineral wastes with little effort expended on their value as construction and industrial minerals. If industrial applications could be found for mineral waste it would improve the profitability of quarrying operations and improve the efficiency of resource utilization. This paper considers two recent research projects carried out by the British Geological Survey that aimed to develop industrial mineral applications for mine and quarry waste.

REFILL

Background

Leahill Quarry is located on the coast of SW Ireland (near Adrigole, Co. Cork) in an Upper Devonian gritstone (fine-grained sandstone) sequence that is worked to produce high specification crushed rock aggregates (exported into UK and mainland Europe). The nature of the rock results in large quantities of fines being produced during processing. Leahill Quarry produces about 270,000 tonnes per annum of fines (0-2mm materials) and 'filler' (material passing 75µm) after processing (washing). In an attempt to find new outlets for Leahill fines, Tarmac Fleming and BGS took part in a three year EC–supported industrial research project called REFILL, which included other UK and Greek partners and was managed overall by MIRO (Mineral Industry Research Organisation). Further details on the project are available by contacting MIRO through their website at: www.miro.co.uk.

The REFILL project consisted of various tasks which involved both Tarmac Fleming and BGS. Tasks 1 to 3 involved a study of existing production practices and a programme of technical evaluation of the fines from Leahill and other quarries in Britain. This involved characterization of the mineralogical, physical and chemical properties of the residues. Task 4 was a large-scale continuous test at Leahill Quarry to determine the effectiveness of a novel fluidised bed plant in terms of its ability to extract 'filler' from the 0-2mm fines. Tasks 5 to 8 investigated the potential end uses that could incorporate Leahill filler and fines, including an assessment of the available resources of fines, the availability of fines acceptable for particular applications and a review of the market potential for end-uses including asphalt, concrete, artificial soils and non-plastic sub-base materials.

In total 128 samples of quarry fines were collected from 30 sites operated by Tarmac in the UK (including Leahill Quarry in Ireland) during the first year of the project. These sites work a range of hard rock and alluvial/ marine dredged sand and gravel. 102 samples were characterized and a one-page 'characterisation factsheet' produced for each sample. This includes a summary of the mineralogy, chemistry and particle-size distribution plus information on the locality, geology and sampling methodology. The literature gathered during the project forms a reference 'library' which has been catalogued using bibliographic software (EndNote ®) and is currently being updated.

The fines from Leahill are highly consistent; they mainly consist of quartz with chlorite, alkali feldspar and mica, and have a 'filler' content of 19 to 23 wt%. The fines samples collected from the UK quarries represent a range of lithologies including sand and gravel (land and marine), sandstone, limestone, dolomite, trachyte lava, diorite, dolerite and granite. Their mineralogy and chemistry broadly reflect the lithology of the worked material. Their particle-size distribution partly reflects the lithology but mainly the degree of processing the material has undergone. Generally samples of precipitator and lagoon fines have high 'filler' contents, ranging from 75 to 93%, whereas samples of plant fines have lower 'filler' contents, ranging from 10 to 16%.

The research carried out on potential end-uses for the Leahill Quarry fines was focused on those that would make use of the fines without significant reprocessing. The next part of the paper will discuss the development of new markets for Leahill fines including; asphalt, concrete and in particular 'synthetic soils'.

Product Development

The main technical barrier associated with the use of Leahill fines in asphalt and concrete was its high 'filler' content (typically up to 23%). It was hoped that a novel fluidised bed plant designed and installed by Torver Engineering would be able to remove sufficient 'filler' from the 0-2mm fines (for subsequent use as replacement filler) to enable its use in asphalt and concrete. Unfortunately, the plant operating conditions necessary to remove sufficient 'filler' from the 0-2mm fines proved to be uneconomic and the Torver plant has since been de-commissioned. An alternative strategy was developed and adopted to wash the 3mm single size aggregate and to blend this with the 0-2mm fines. This had the effect of reducing the 'filler' content in the fines to acceptable levels for use in asphalt and concrete i.e. typically 12 – 15%. More recently, the 0-2mm fines are being washed to further reduce the 'filler' content. The filler-grade material removed from the fines is being stored in managed lagoons, which in itself creates a future disposal issue.

The asphalt laboratory assessment work focused on incorporating the Leahill 0-2mm fines in typical surface (wearing) course asphalt mixtures and examined its impact on asphalt durability. After testing the mixtures using a rigorous compliance procedure developed by the British Board of Agremont, it was concluded that Leahill 0-2mm fines (unwashed) are unsuitable due to the high filler content (23%). However, subsequent testing on blends of fines with washed 3mm single sized aggregate proved to be successful; probably due to the reduction in filler content to 15%. Hence this blend was approved for use in asphalt mixtures, including premium asphalt materials.

Extensive laboratory testing on concrete mixtures, incorporating Leahill 0-2mm fines, focused mainly on assessing initial mix properties to determine suitability. This was done in accordance with Tarmac's in-house procedures for checking any new source of fine aggregate proposed for use in structural readymix concrete. No test work was done to assess suitability in concrete blocks because Tarmac Topblock Ltd advised it was extremely unlikely that Leahill 0-2mm fines would be economically viable due to competition from 'other' sources of secondary or by-product fines e.g. Furnace Bottom Ash from coal powered electricity generation plants. The research work concluded that acceptable concrete mixes could be made which incorporated Leahill 0-2mm fines blended to an ‘M grade’ sand grading. Using 100% Leahill fines, even when blended with washed 3mm grit, proved on the whole to be unsatisfactory in terms of workability, compressive strength and water demand (which influences long term durability).

Artificial soils

The suitability of quarry fines in artificial soils was evaluated by Harper Adams Agricultural College based near Newport, Staffordshire. Artificial soils are essentially designed blends of mineral dust and composted green waste. In these trials, the green waste was derived from three different sources i.e. green waste, composted paper pulp, and composted tannery waste. Extensive testing was carried out under greenhouse conditions in ‘pots’ and in large-scale ‘open air’ plots. The ‘pot’ trial results were very encouraging; hence it was decided to install a larger scale trial at Tarmac’s Seisdon quarry in Staffordshire in May 2001. The main aim of conducting larger-scale trials was to evaluate the ability of a range of artificial soils to support both grass and tree growth. These large-scale trials are still continuing as part of the research to evaluate long-term performance. Leahill 0-2mm fines (and 3mm single size aggregate) are being compared with other quarry fines supplied by other Tarmac quarries in the Midlands.

<u>Greenhouse pot growth trials</u>

The greenhouse pot trials used green waste compost, quarry fines and/ or 3mm aggregate in varying blends (volume basis) as a growing medium for grass. The ‘total mean fresh weight’ of grass harvested per pot is given in Table 2. The results are an average of all three composts tested for each of the soil blends. The growth media have been ranked in order of performance. The ‘first-grass’ harvest data taken after 3 weeks growth shows that blends of green waste compost and Leahill 0-2mm fines were far superior to the blends in which Leahill 3mm aggregate was included. However most blends produced only half the weight of grass compared to the ‘control’ compost, which highlights a shortage of nutrients in the artificial growing media blends. Soils manufactured from composts and quarry fines will need to be supplemented with fertiliser to achieve good establishment and medium-term growth for a range of plants. Harper Adams is currently researching the best fertilizer(s) to use.

Growth medium (ranked)	**Fresh grass yield per pot** (grams)
1. Control	1.83
2. 2-parts compost, 1-part fines	1.14
3. 1-part compost, 2-parts fines	1.04
4. 4-parts compost, 1-part fines, 1-part aggregate	0.91
5. 1-part compost, 1-part fines, 1-part aggregate	0.77
6. 2-parts compost, 1-part aggregate	0.68
7. 1-part compost, 2-parts aggregate	0.54

Table 2. Pot Growth results for artificial soils made with Leahill fines

Based on the pot growth trials, the Leahill 0-2mm fines blended with composted green wastes produces a growing media comparable in performance to other sources of quarry fines blended with the same sources of compost. The mineralogy of the Leahill fines, i.e. high silica content, is well suited to inclusion in growing media. The addition of a suitable fertiliser will be required to increase the nutrient availability to marketable levels.

Larger-scale ‘open-air’ growth trials

The large-scale open-air trial at Tarmac’s Seisdon quarry aimed to evaluate the establishment of turf and trees on synthetic soils created by mixing 1-part compost with 2-parts quarry waste fines. Raised-bed plots (2.5m x 2.5m) were created and seeded with amenity turf grass and planted with six trees; two willow, two birch and two alder. The plots were evaluated in October 2001 for plant establishment. Grass and tree growth is being assessed at regular intervals as well as other parameters i.e. depth of root growth and leachability of nutrients.

The physical characteristics of the artificial soils were compared with the quality requirements contained in BS 3882 and were shown to meet the criteria for ‘economy grade’ soils. The ‘growth’ results for Leahill artificial soils and a control top soil is summarized in Table 3. ‘Grass’ development was scored on overall appearance and cover on a scale of 1 to 5 (5 being best). The soil blends performed well in terms of grass development, comparable to the control topsoil. The ‘Tree Score’ was best with soil made with tannery waste, performing better than the control topsoil. Measurements of the soil shear strength showed that synthetic soils made with paper compost were better than the control topsoil.

	Leahill fines with green waste	**Leahill fines with paper waste**	**Leahill fines with tannery waste**	**Control top soil**
Grass Score	2	2	2	3
Tree Score	4.5	4.5	5.5	5
Initial Shear Strength (kPa)	53	90	70	74
Final Shear Strength (kPa)	93	97	75	76

Table 3. Large Scale Plot Growth Results for Leahill Artificial Soils and Top Soil

Discussion

Progress to date has been very promising with results demonstrating artificial soils can perform to a level expected of economy grade soils in terms of supporting grass and tree growth. Tannery waste compost has twice the nitrogen content of the other composts, which is believed to be the main reason for its superior performance regarding tree growth. The addition of fertilizer nitrogen to some blends (e.g. composts containing <1% total N) should improve tree establishment (although this would then accelerate grass growth as an unwanted side effect). Further research is required to determine the ecological safety of these artificial soils, based on the cumulative effects of low levels of contaminants e.g., heavy metals on soil biota. Appropriate tools for assessing the soils using invertebrate indicators (e.g., enchytraeid worms) are the subject of a current joint research project.

MINERALS FROM WASTE

Mining operations are often the lifeblood of small communities, if this is true in western society it is even more so in less developed countries. In these countries, mining communities are often established and populated by migrant workers lured by the prospect of work. These workers and their families set up their homes within the vicinity of the mine site. The prosperity and well being of these communities is linked to the success of the mine. The production of saleable mineral products from the waste produced by the mine would provide further employment and sustain the community. This may become a lifeline when the worst-case scenario, such as closure of the mine, occurs and would help to mitigate the inevitable unemployment and poverty.

The 'Minerals from Waste' project aimed to improve the sustainability of current and former mining and quarrying activity by investigating the utilization of mineral waste as a source of construction and industrial minerals. The project (1999 – 2002) was funded by the UK Governments Department for International Development (DfID) as part of their Knowledge and Research (KaR) programme which forms part of the UK's provision of technical aid to less developed countries. The project summary report is available to download from the BGS website at: www.mineralsuk.com/mineralsuk/free_downloads.html.

A scoping study (Harrison *et al*, 2001) was conducted to review the types of mineral waste found in extractive operations from which marketable construction and industrial minerals could be recovered. These are summarized in Table 4.

Quarrying operation	**Potential products/ minerals from mineral waste**
Hard rock & building stone	Aggregate (+ lightweight aggregate), aglime, artificial soils, glass and ceramic raw materials, fill, mineral filler, stone paving/ tiles and synthetic stone.
Sand & gravel/ silica sand	Ceramic and brick clay, fill and fine aggregate.
Coal	Brick clay, fill, lightweight aggregate and road base.
Kaolin	Fine aggregate.
Mineral sand	Garnet, sillimanite, staurolite and monazite.
Pegmatite	Feldspar, mica, quartz, lithium minerals, beryl, kaolin and bentonite (white).
Talc	Limestone/ dolomite, magnesite and decorative stone.
Phosphate (carbonatite-hosted)	Fluorite, vermiculite, phlogopite, mica and limestone/ calcite (host rock).
Metal	Large variety of geological settings and likely industrial mineral by-products.

Table 4. Mineral waste settings and potential industrial products

Methodologies were also developed to assess the economic, environmental and social issues involved in mine waste utilization. These were implemented via a series of case studies at several former and current mining sites in Costa Rica and Namibia, two of which are summarized in the following sections.

Silica sand waste, Costa Rica

Silica sand for glassmaking is quarried and processed by SICORSA near Cartago in central Costa Rica. Current operations involve attrition scrubbing, hydrosizing and magnetic separation to reduce the iron and clay content of the sand. Approximately 50,000 tonnes of mineral waste are produced annually as tailings. The tailings lagoons are reaching their design capacity and with little room for additional waste storage it would be beneficial if end-uses could be found to reduce the waste volumes.

The tailings in some parts of the lagoon consist mainly of fine-sand grade quartz with minor amounts of the clay mineral, kaolinite (the clay content in other parts of the lagoon is much higher). The clay-rich tailings were assessed, alongside commercial clay from a local brick works, to determine their suitability for use as brick/ ceramic clay (its use for whiteware ceramics was rejected as it fired to a red colour). The forming and firing properties were found to be similar to those of the brick clay used locally and indicate that bricks/ ceramic products (such as tiles, pipes & pottery) could be made from the clay-rich tailings.

An economic appraisal indicated that the demand for bricks in Costa Rica is small and that production of bricks from the tailings would not be economically viable. However, the economic viability would be more positive if the indirect cost benefits of reducing the need for waste storage and additional revenues from recovery of silica sand were included. Overall the socio-economic impacts of such a scheme would be low with the mitigating benefits of additional employment and improved local transport infrastructure for the local communities. Current plans for the silica sand waste include its use in ceramic tile manufacture and the production plant should be operational late in 2003.

Pegmatite mine waste, Namibia

The tin mine at Uis in central Namibia ceased operations in 1990. During the life of this operation, cassiterite and a small proportion of tantalum-bearing minerals were recovered from quartz-feldspar pegmatites using a gravity processing plant. The processing operation left behind somewhere in the region of 75 million tonnes of mineral waste, present in coarse-grained tailings heaps and fine-grained tailings lagoons.

The tailings consist largely of sand- and silt-grade alkali-feldspar and quartz with a small amount of muscovite mica. Laboratory processing trials demonstrate that industrial grade mica and silspar (a ceramic raw material consisting of roughly equal proportions of feldspar and quartz) could be produced from the tailings using simple dry classification methods. An economic appraisal indicated that the main markets for these products would be South Africa via overland transport or the international market accessed through the port of Walvis Bay. The viability of a modern high-capacity production plant (2500 tpd), including air classifiers, froth flotation and magnetic separators, could not be maintained if the sole market was South Africa. To maintain the economic viability of such an operation the mineral products would need to be of the highest quality in order to satisfy the standards of the international market. An alternative artisanal scenario, which would use appropriate processing technology and only process small volumes (100 tpd) of mineral waste, would have more marginal profitability.

The local community has a large number of former miners and is positive about the prospect of mineral waste utilisaton as it represents employment opportunities. Recommendations were made to the Namibian Government in support of a mineral waste scheme. There is already active support for the former miners via the Small-scale Miners Assistance Centre, which established a small processing plant for the recovery of tin/ tantalite in 1996. Promoting local employment, dust control measures and programmes to minimize the risk of a ‘boomtown’ scenario would help to mitigate the socio-economic impacts of a mineral waste scheme.

Conclusions

The reuse of mineral waste is desirable from a social and environmental viewpoint but also needs to be economically and technically viable. Benefits for reuse of mineral waste include:

- Efficient use of resources
- Reduced environmental impact
- Increased profitability (increased income & reduced disposal costs)
- Improved sustainability for local communities

The methodology established in these research projects for determining the feasibility of mineral waste reuse has integrated technical, economic, environmental and social assessment. Geologists now find that their work on natural resources increasingly coincides with that of industrial mineralogists, mining engineers, mineral planners, market researchers and social scientists.

Reuse of mineral waste is being driven by economics. The motivation for this research has been spurred on in recent years by the introduction of taxes on disposal and primary construction materials. Ultimately, profitability will depend upon innovative research and new applications for reuse of mineral waste as well as a consideration of the wider world beyond the mining industry.

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Published in Elsevier.
IPR/48-3C