A study on best available techniques for the management of stone wastes

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ABSTRACT

Natural stones are extensively used for construction purposes since the dawn of human civilization, due to their unique aesthetical and technical characteristics. Their production and consumption has been continuously increasing over the past twenty years worldwide at an annual rate of 8.8%. European countries lead the race of per capita consumption, with Switzerland being in the first place with a consumption of 144.7 m^2 per hundred inhabitants followed by Greece, Spain, Portugal, Belgium and Italy. On the other hand, during the period 2001-2002 the generated stone wastes were 110 million tones according to EU data, from which only about 5 million tones were recycled or re-used mainly in the construction industry. These stone wastes the non-natural wastes such as oils or chemicals coming from the equipment and machinery employed for stone extraction and processing, are disposed in the environment, posing serious environmental threat.

To achieve sustainable development of the stone sector appropriate methods that will prevent or reduce waste generation and disposal have to be identified and applied. In this work an extensive study of the stone waste management techniques applied in Europe is carried out, in order to identify the Best Available Techniques (BAT) that can be used according to the type of generated wastes and the waste management hierarchy: Waste minimisation, Reuse, Recycling and Disposal.

The identification of BAT was performed based on 14 Sustainable Development Indicators (SDI), which were grouped into three categories: environmental, economic and social. The developed final list of BAT includes waste minimisation techniques, eco-management schemes, in-situ treatment and appropriate storage and selection.

1. INTRODUCTION

The waste management aims at the prevention or reduction of wastes production or the danger from them, especially through: the reuse of wastes, the control of the productive processes, the adoption of cleaner technologies, as well as the appropriate sensitization of the economic authorities and consumers. At the same time, the proper management of wastes aims to assure their re-use through recycling, or adequate elimination. Management of industrial wastes is an issue of high importance for Europe. For this reason and in order to ensure the sustainable development of modern society, Europe is promoting activities to protect the environment.

During the operation of a stone quarry or a processing plant the production of wastes is inevitable. These wastes can be classified in two groups, those produced directly from rock extraction and processing, which correspond to stone materials without commercial value (inert wastes) and the wastes resulting from the equipment or subsidiary materials such as metal wastes, used oils, etc.

Quarrying operations generate large quantities of stone wastes due to the very small recovery ratio. In addition, significant quantities of wastes are also produced during the cutting and sawing phase of stone processing. These wastes have important environmental impacts and their management is fundamental to achieve the sustainable development of stone industry.

This paper presents the work performed for the identification of the Best Available Techniques for stone waste management according to the waste type and the waste management hierarchy: waste minimisation, re-use, recycling and disposal. For the identification of BAT 14 environmental, economic and social SDI were used.

2. WASTE MANAGEMENT

2.1 Overview

The amount of waste generated from the exploitation of natural stones (mainly marble and granite) is one of the most important problems in this industry sector. Quarrying activities which include the extraction of stone resources can deliver from 50 to 95 % waste material (OSNET vol. 2, 2003) while in the subsequent phases of processing up to 41 % (Stone, 2004) of the original input material is turned into waste.

Data for 2003 concerning the world stone production indicate that the net quarry production was 75,000,000 tons per year while the respective amount of generated waste was 78,750,000 tons per year, which corresponds to 51% of gross quarry production. Taking also into account the amounts of waste from the subsequent processing phases, the total amount of stone waste was 109,500,000 tons per year while the corresponding amount of finished product was 44,250,000 tons per year (Stone, 2004). In 2003, the EU alone accounted for 29.2% of the total amount of stone produced worldwide corresponding to 21,900,000 tons of stone materials and 22,995,000 tons of quarry wastes (Stone, 2004).

As it can be seen from these figures the amount of wastes produced is enormous compared to other extractive sectors as the aggregate or industrial mineral sectors. In these two sectors wastes are mostly used in temporary quarry modulation works (i.e. ramps, access roads, etc.) or as filling material for the quarry rehabilitation. These solutions are also used in the stone sector but cannot completely alleviate the problem, since a more integral approach is needed. Below, three different approaches philosophies are presented, which have been developed through the years of trying to solve the problem of waste management.

2.2 Final destination philosophy

The responsibility for the final destination of the residues is of who produces them, without damage of the responsibility of each one of the operators in the measure of its intervention in the circuit of management of these residues and except for what specific legislation determines. Regarding the possible final destinations of wastes, the legislation defines a hierarchy of preference based on which of the following destinations are considered:

- Source reduction.
- Recycling.
- Land filling/Elimination.

A proper waste management plan applied by the extractive industry must include the following aspects:

- To prevent or reduce the production of wastes and their dangerousness, by:
  - management of the wastes in the phase of production and proper selection of the extraction and treatment methods;
  - good control of the alterations that wastes can suffer at the surface;
  - replacement of the stone waste (backfilling) after the extraction of blocks, in the measure of practicable;
  - replacement of the superficial ground, after the backfilling, or reuse of the soil in other place;
  - use of less dangerous agents for the treatment of the mineral resources.
- Motivate the recovery of the residues by recycling, reuse or valuation, in the respect of the environment.

2.3 Uncoordinated or Coordinated waste management

According to what is known and practicable nowadays, there are two waste management approaches applicable to the enterprises of a determined industrial centre: the "Uncoordinated waste management scheme" and the "Coordinated waste management scheme".

The uncoordinated waste management is the only possible solution for enterprises geographically distant but presents higher environmental impacts from the cumulative actions of all, higher economical and environmental costs and lack of coordination.

The coordinated scheme involves the coordination of the waste management activities of all enterprises operating at the same site in order to minimize the environmental impact and provide greater control over the waste management. On the other hand, the presence of a coordinator is necessary which creates extra general costs for the enterprises.

2.4 Waste management hierarchy

The waste management hierarchy can be tracked back to the 1970s, when the environment movement started to criticise the practice of disposal-based waste management. Rather than regarding "waste" as a homogenous mass that should be discarded, the different options of treatment, i.e. minimization, reuse, recycle should be considered first. In detail, the waste management hierarchy is ordered as follows (Pongracz, 2002):

- Waste minimization
- Re-use
- Recycling
- Disposal

The short version of the hierarchy "Reduce, Reuse, Recycle namely the "3 R's" is frequently used in community education campaigns and has become a well-recognized slogan for waste reduction and resource recovery (Gertsakis and Lewis, 2003).

However, this hierarchy was revised and according to directive 91/156/EEC (Article 3), EU Member States should take appropriate measures to encourage:

- The prevention or reduction of waste production and its harmfulness;
- The recovery of wastes by means of recycling, re-use or reclamation or any other process towards extracting secondary raw materials;
- Safe disposal of wastes.

Management policies based on this hierarchy seek to maximize the minimization of waste generation and the recovery options and to minimize disposal through open dumping and landfilling. Once possibilities for recovery have been exhausted, policies favour safe disposal, limiting negative impact on the environment and on natural resources as much as possible.

3. SUSTAINABLE DEVELOPMENT INDICATORS

The goal of sustainable development is to promote economic activity with environmental integrity, social concerns and effective institutional systems, in a way that meets the needs of the present without compromising the ability of the future generations to meet their own needs. In order to assess the progress of a human economic activity towards sustainability a set of Sustainable Development Indicators (SDI) is needed. To create a suitable set of SDI for the evaluation of the sustainable performance of the stone waste management strategies, a number of scientific and technical criteria have been set and are presented in the following list, which an indicator needs to satisfy:

- Representative;
- Simple and easy to interpret;
- Show trends over time;
- Sensitive to the changes it is meant to indicate;
- Be based on readily available data or be available at reasonable cost;
- Be based on data adequately documented and of known quality;
- Be capable of being updated at regular intervals;
- Have a target level or guideline against which to compare it;
- Be SMART, i.e. Specific (or Clear), Measurable (or Quantifiable), Achievable, Relevant and Time-framed (PMBOK Guide, 2000).

Table 1 presents a list of fourteen indicators grouped into three categories: environmental, economic and social. These are the SDI selected for the evaluation of the stone waste management schemes in order to derive the BAT.

4. BEST AVAILABLE TECHNIQUES

According to the "3 R's" waste management hierarchy the BAT for stone waste management, which serve the goals of protection of the environment and human health and conservation of resources, are identified for each one of the hierarchy categories (i.e. reduction, recovery and disposal).

4.1 Waste reduction

Stone waste reduction at the origin is possible through the use of equipment that allows maximizing the exploitation of stone and therefore minimizing the waste production. There are many types of equipment and technologies that permit waste reduction. In this group are included the diamond tools, which are used in circular tools, gang saws and wire saws. Diamond tools offer better performances, save time and money and are very important for waste reduction. In this direction, research is currently in progress with promising results, for the production of thinner and faster cutting and drilling tools that will make the waste production even smaller.

Table 1: Sustainable Development Indicators.

Category	Indicator	Unit
Environmental	1. Specific volume of stone waste managed	t/m^3
	2. Indicative water consumption during treatment per tonne of stone waste	m^3/t
	3. Energy consumption	High/Low
	4. Chemicals/Reagents consumption	High/Low
	5. Use of dangerous substances (reagents, chemicals)	Yes/No
	6. Transport constraints (average transport distance from source to customers)	High/Low
	7. Environmental incidents (reportable)	Number
Economic	8.Overall indicative treatment and handling costs	High/Low
	9. Indicative capital costs of waste management facilities (if applicable)	€
	10. Indicative savings from landfill fees and rehabilitation costs	€
	11. Total R&D expenditure/turnover	%
	12. Profit making/Added value	High/Low
Social	13. Direct and indirect employment	Number
	14. Risk for accidents	High/Low

Besides using modern equipment, changing the exploitation method is also another way to reduce the quantities of waste produced. Underground exploitation is being more and more implemented by quarry operators with very good results. The path towards this method was opened mainly in the framework of an EC funded research project; the equipment (gallery saw) and methodology developed are being used nowadays in underground quarry exploitation.

Stone wastes anyway produced in the quarry can be properly treated by means of:

- Use of cutting equipment in situ for performing adjustments to irregular blocks that otherwise would be discarded, transforming them to marketable products.
- Establishment of a stock area in order to prevent the concentration of materials in dumps and landfills.
- Acquisition of a mobile crushing plant that can be used in common by more than one enterprise for the production of aggregates.
- Non-commercial pieces can be used in access roads or slopes in the quarry area.

Concerning the processing plants, the use of specific techniques for the reduction of the rejected blocks or slabs are being considered. Such a technique is the use of environmental friendly agents for the reinforcement of mechanically unsound or aesthetically poor blocks, that otherwise would be discarded. Techniques that collect waste (mostly in the form of dust or mud) produced from the stone processing are also employed by the enterprises in order to minimize the impacts in the plant environment and reduce the probability of industrial diseases.

To control and prevent the production of mud, special measures and procedures should be adopted which include:

- Selection of the best available equipment for the decantation and pressing of mud;
- Creation of zones in especially selected regions, where storage and efficient management of mud can be performed, with the possibility to form a stock market of raw materials for other industry sectors;

- Correct storage of the mud inside the company area;
- Transportation of mud by specialized companies to suitable places in order to prevent accumulation of great volumes in non-appropriate areas.

4.2 Waste recovery

There are various options for recovering stone wastes (Fig. 1) depending on the type (e.g. the size) of the stone element. Quarry wastes are classified in four types according to their size: third choice blocks, large shapeless blocks ($\geq$0.2 m^3), small shapeless blocks ($\leq$0.2 m^3 or dimension < 0.5 m) and the small to fine size particles.

Third choice blocks can be used in the production of low price elements for external uses such as pavements, kerbs, and dry wall construction or they can be stored and occasionally processed accordingly to the market demands for large quantities of elements without high qualitative standards. In addition, if the blocks cannot be used in neither of these uses, they can always be crushed and used as aggregates.

Large shapeless blocks can be used mainly as armourstone. This is a practice followed when the natural material has the necessary physical-mechanical properties (mainly hardness and strength) or otherwise the blocks can be crushed for aggregates. The most suitable option for re-using small shapeless blocks is the production of aggregates by crushing.

Small size particles like sand or fines that are produced during the block extraction operations or by crushing larger sizes of stone waste can be used either in manufacturing of various construction admixtures, plasters and fillers or they can be used to produce industrial minerals. Calcareous wastes due to their high $CaCO_3$ content can be used to extract lime for industrial or agricultural use while granite can be used to extract silica sand.

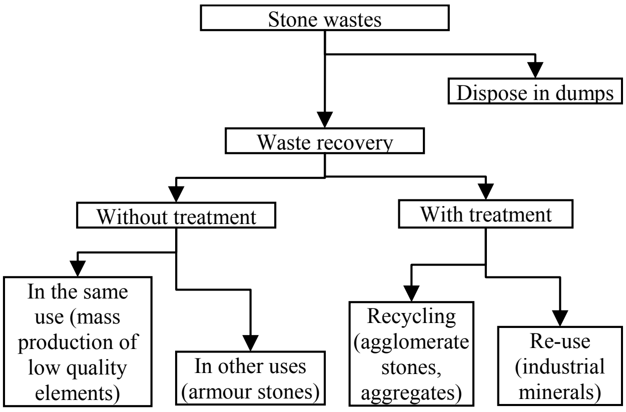

Figure 1: Management schemes for stone wastes.

On the other hand, processing wastes are classified in three types: large to medium size wastes called scrap, medium to small size splints, flakes, chips and small size wastes consisting of fine particles in the form of dust or sludge. Large size scraps can be exploited by specialized companies which separate them by material (marble, granite and stone), colour and surface finishing (polished, honed, sand blasted, flame textured, etc.). Choice and good quality scraps have their own markets and are used to make low-cost rustic floorings and coverings, generally for outdoor applications. In particular, rough textured granite scraps (flame or water jet processed, etc.) are in great demand in some northern countries, where they are used to make hard-to-wear, non-slipping external floorings and can reach good prices (5-8 euros/m^2). Non-choice scraps can be crushed into aggregates for the building industry (Davini, 1998).

Small-medium size chips (strips, splints, etc.) are usually sent to a crusher unit for aggregates (which is often very expensive), or they are crushed into stones or building or gardening materials, and, in some cases, they are also used as land-fillers for agricultural purposes.

Sludge has specific particle-size, composition and features. These properties are related to the material that sludge comes from (type of marble or granite, etc.), the processes (cutting, polishing or finishing, etc.), the type and the grain size of tool used in the process (diamond, emery, etc.) and the processing variables (speed, motion, etc.) They determine the subsequent options for recovery. For example, only white marble sludge can be used in the paper industry because of the very specific requirements of paper. Calcareous sludge can be used to neutralise acidic industry by-products or contaminated agricultural land or to de-sulphurise the fumes produced by high-power thermoelectric plants, in construction industry as additive in hydraulic mixtures, plasters, fillers. Sludge can also be dried and sieved for shipping to users of calcareous materials specialising in: paper fillers, polymeric fillers (PVC), water paints, bitumen sheaths, etc.

Granite and marble sludge can be used as land-fillers: large swampy areas have been filled with these materials in the past. Granite sludge produced by disk saws or by the polishing process has low iron content so, after drying and sieving, it can be directly used in a number of applications such as the ceramic industry or as filler in the moulding of plastics (PVC) when the inert material does not need to be calcareous. Sludge resulting from sawing of granite blocks with metal grits (that contain large amounts of iron) is dried in special furnaces and then is separated from iron by strong magnetic fields and by the difference in density between the iron and the inert material. The replacement of feldspar in ceramics production with granite sludge is constantly gaining ground during the last years (Bozadgiev, 2000).

4.3 Waste disposal

As far as the disposal of quarrying waste in dumps is concerned, stone industry uses some practices that have been proven good solutions for the waste disposal problem. A good practice, especially when many quarries are operating in the same area, is the use of common disposal sites. These sites though must be carefully selected in order to take advantage of the topography, without causing soil instabilities or change the water courses (OSNET vol. 12, 2004).

Another practice that is also indicated as best solution is the backfilling of the voids created by extraction with the waste material. However, in most cases this can take place only after the quarry closure and not during its operation due to the fact that the exploitation of a stone deposit usually has a downward direction rather than a lateral thus rendering backfilling completely impractical. Regarding the wastes resulting from processing plants the most significant is sludge (water and stone dust). Sludge causes the most important problems and can be disposed off in a dump near the factory or used in land levelling operations.

5. CONCLUSIONS

The best available techniques for the management of stone wastes in quarries and processing plants are divided in two groups.

The procedures and equipment that are applied and used in stone quarrying and processing that allow the prevention and reduction of waste production belong to the first group. Every advance in the equipment or in the methodologies with the objective to improve the exploitation of the stone is directly proportional to the minimization of the waste production.

The second group includes all the applications that permit the recycling and reusing of the wastes. Stone wastes, mainly the ones produced in bigger quantities (stone without commercial value and sludge) keep the chemical characteristics of the original rock therefore with more or less processing they can be used as secondary raw material in other industries like the chemical and paper industry or agriculture.

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