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ENVIRONMENTAL AND ECONOMIC JUSTIFICATION OF DIMENSION GRANITE CUTTING TECHNOLOGIES

KEYWORDS: dimension stone, cutting techniques, economic efficiency, quarry LCA.

INTRODUCTION: The morphological and geologic variability of stone deposits and natural differentiation of the materials give the reason for the huge spectrum of typologies of quarries that can be found also within the same geographical area. As a result, a range of technical solutions developed and adopted for stone quarrying is extremely wide [1]. The generalized productive cycle and main techniques employed at high-strength dimension stone quarries are shown in Fig. 1.

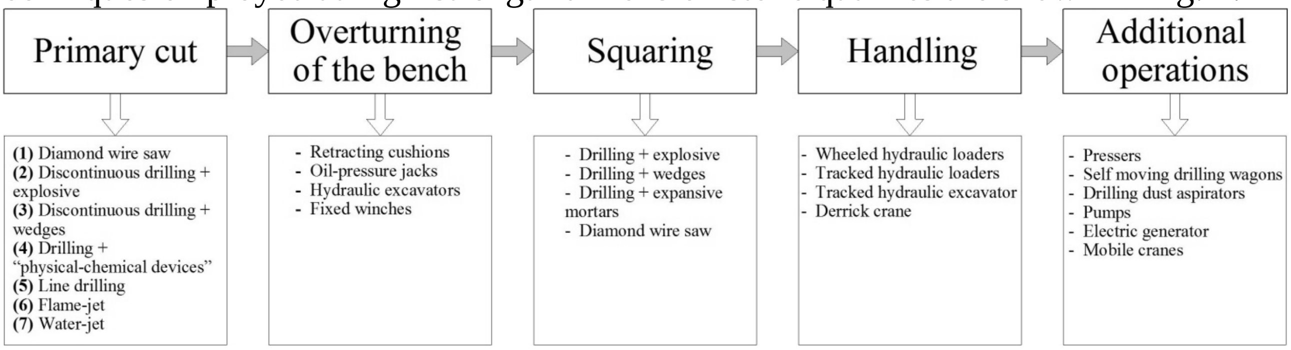


Figure 1. The productive cycle of granite quarrying and principal technologies currently in use

Hence, referring to Fig. 1, methods (4-7) are probably destined to be less and less employed due to a variety of reasons: rather long action time, high dependence on environment conditions, large volume and high value of drilling operations, necessity of a professional maintenance, notable environmental impact (in terms of energetic consumptions, elevated noisiness, aerodispersed dusts, exhausted gas), etc. Consequently, the most widespread techniques are (1-3) [1–3]. Nevertheless, there is a lack of explanation on the (1) and (2) techniques performance in monetary and environmental terms in aggregate. In hard stones quarries, some problems mainly related to the abrasiveness of the materials are limiting the use of diamond wire cutting technology (DWS). The combination (2) is probably the most traditional, consolidated and "cheap" technique in the exploitation of hard stones [1]. However, not only should low production costs be taken into account, but also the method's recovery; that is, how much of the quarried stone will be really exploitable in further processing [4].

The choice of explosive is made accidentally at many dimension stone quarries through a direct transfer of experience from other similar companies. This experience has not always been successful, so far powder or detonating cords are mainly used. Many explosives could not be widely used for dimension blocks extraction because of considerable fractures creation in the rock mass [5]. Consequently, the current study objective is to help producers in detecting the most appropriate techniques for dimension stone deposits both from the economic and environmental points of view.

METHODOLOGY: This paper aims to give some suggestions to evaluate which are the best techniques for an economically and environmentally sustainable supply chain of natural stone. The methodology proposed here is characterised by a comprehensive approach, which take into account the techniques from their real beginning (such as the production of tools) to their real ending (e.g. the treatment of wastes). This is the, so called, Life Cycle approach, which, extending the boundaries of the analyses, allows to understand whether changes in processes lead to real benefits or they just shift costs and/or environment impacts from one phase to another one. This methodological approach has been applied to aggregates production in SNAP project (http://www.snapsee.eu), a research study to enhance aggregates planning and management processes. According to SNAP manual, the main information to be collected is the extracted volume, types of employed materials, the waste production and the location. Since to make decisions about a good management of quarries, it is necessary to face multicriterion problems, the approach described here intends to give guidelines to help the understanding of this complex system, the subdivision into simpler issues and its re-composition and weighting to pursue the best techniques according to the specific conditions of the quarry.

Techniques employed at some Ukrainian and Italian dimension stone deposits were examined. Performance data of granite excavation techniques was measured, in order to determine which of them are the most economical. The primary cut of blocks was analysed using two alternative techniques: diamond wire cutting (1) and discontinuous drilling + explosive (2). Operating and financial statements and material resources turnover of several granite deposits were analysed. The principal parameters of appraising the effectiveness of DWS technique are cutting speed (m^2/h) and service life (or productivity or yield of the wire, m^2/m). These two parameters have to be examined simultaneously to decide if the choice to use the wire as cutting technology is economical.

From the environmental point of view, the standardised method of Life Cycle Assessment (LCA) is employed as a tool to evaluate the environmental impacts of the stone processes. LCA analyses are regulated by the ISO 14040-44 standard and investigate all the physical exchanges between the production system and the environment. According to the standard, it is necessary to develop an inventory analysis to provide a detailed description of the inputs of raw materials and fuels into the system and the outputs of solid, liquid and gaseous wastes of the system. Since this is the base for the next phases of impact assessment and interpretation, it is important that inventory data of the processes taking place in quarries are as representative as possible. Nevertheless, in LCA databases (such as Ecoinvent, Thinkstep, ELCD), the availability of data related to quarries activities is quite limited. Therefore, the risk is to reach the results which are not really significant. To fill this gap, environmental investigations concerning the main quarrying techniques and tools are under development. The goal is to provide LCA databases with datasets which can be easily customised to the specific cases. There are ongoing investigations, for example, to define the environmental impact of diamond wires and explosives.

RESULTS: In order to better evaluate the economical and environmental efficiency of quarrying processes, the most common techniques are currently analysed. In this paper the results concerning the diamond wire use are shown.

With reference to 1 m^3 of stone, the use of explosives is cheaper than DWS technique. However, the problem to correctly appraise its unitary cost with reference to the volume of useful blocks produced must not be neglected (see Fig. 2). In comparison to (1), (2) causes a greater percentage of waste (7-10%) in contrast with 2-2.5% [1]. Since the commercial value of the stone grows with the processing progress, a less precise method could be advantageous only at the initial stages. Besides cheapness of the technique, other aspects have also to be considered: the safety, the operative flexibility and the adaptability to the characteristics of the rock, the minimization of the environmental impacts, etc.

From the environmental point of view, as explained in the previous paragraph, materials are investigated with a Life Cycle approach. It means that the diamond wire is considered throughout the phases of production, usage, treatment of wastes or disposal. Diamond wires comprise a metal rope on which synthetic diamond beads are mounted at regular intervals interposed by rubber or plastic annular layers. Diamond beads can be sintered or electroplated on a metal matrix, whose chemical composition often contains heavy metals such as Cobalt and Tungsten. This has direct implications on the wastes impact: dirt from cutting of stone materials usually presents a fraction of about 8% in weight of heavy metals, which are hazardous both for human beings and for environment. Since producers can choose among different kinds of diamond wires and since different variables can be changed according to the extracted stones and the specific working conditions, a parametric LCA model is created. In this way it is possible to customise the environmental assessment according to the specific case, to reach more accurate environmental conclusions and to evaluate possibilities of improvement of the most critical phases.

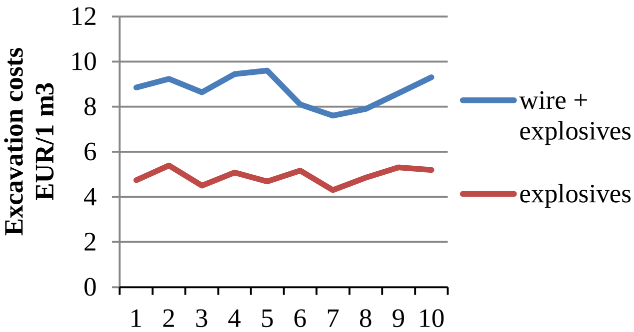
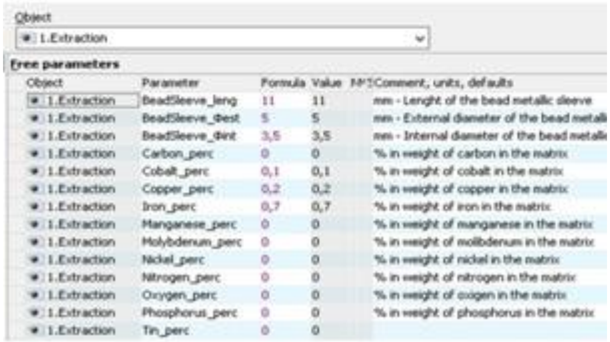


Figure 2. Costs for the excavation of 1 m^3 of dimension granite


Object: 1.Extraction

Free parameters

Object	Parameter	Formula	Value	M?	Comment, units, defaults
1.Extraction	BeadSleeve_leng	11	11		mm - Lenght of the bead metallic sleeve
1.Extraction	BeadSleeve_Φest	5	5		mm - External diameter of the bead metalli
1.Extraction	BeadSleeve_Φint	3,5	3,5		mm - Internal diameter of the bead metalli
1.Extraction	Carbon_perc	0	0		% in weight of carbon in the matrix
1.Extraction	Cobalt_perc	0,1	0,1		% in weight of cobalt in the matrix
1.Extraction	Copper_perc	0,2	0,2		% in weight of copper in the matrix
1.Extraction	Iron_perc	0,7	0,7		% in weight of iron in the matrix
1.Extraction	Manganese_perc	0	0		% in weight of manganese in the matrix
1.Extraction	Molybdenum_perc	0	0		% in weight of molibdenum in the matrix
1.Extraction	Nickel_perc	0	0		% in weight of nickel in the matrix
1.Extraction	Nitrogen_perc	0	0		% in weight of nitrogen in the matrix
1.Extraction	Oxygen_perc	0	0		% in weight of oxigen in the matrix
1.Extraction	Phosphorus_perc	0	0		% in weight of phosphorus in the matrix
1.Extraction	Tin_perc	0	0		

Figure 3. Parameters allowing to set the characteristics of diamond beads

As it can be seen in Fig. 3, quarry industries can change some parameters (such as the dimensions of diamond beads and the chemical composition of the metal alloy) according to the characteristics of the tools they use. This approach requires from the industries a major effort to monitor the characteristics of tools and the consumption of raw materials and energy, but it allows a better understanding of the environmental burdens and it gives indications of the improvements that could be more significant.

CONCLUSIONS: A good economic and environmental management of stone quarries requires the evaluation of many different aspects, sometimes contrasting ones. Different techniques of extraction are available in the stone sector, but the choice of the best ones is not obvious because, as in every complex system, it is necessary to take into account different parameters. Moreover, the context of the quarry could be quite variable and the natural stone not always has constant characteristics. For these reasons it is not possible to define the technique as the best one in absolute terms, but it is necessary to evaluate the specific cases. The life cycle approach can help to make appropriate decisions because of its analyses all along the stone industry processes. From the economical point of view, this approach allows to improve the efficiency of the production, while from the environmental point of view, it avoids shifting the impacts from one phase to another. The principal advantages of the employment of the wire saw are: versatility of use, reduced vibrations, noises, dusts and wastes. The greatest limits are represented by the necessity of a very precise preliminary drilling, the necessity of skilled manpower and of a continuous provisioning of water. Furthermore, cutting by a diamond wire could not be productively applied in case of highly fractured rocks, whereas other technologies are certainly more suitable and cheap. On the other hand, the exclusive use of a diamond wire is not currently practicable in hard stones, where operational problems and costs of production make this method non-competitive in comparison to traditional ones.

From the environmental point of view, the most common quarrying techniques and tools (such as the cutting with diamond wires) are under investigation in order to create customisable LCA datasets able to support the producers in their environmental assessment. Further research is planned in order to provide the stone producers with more LCA data and with a complete model able to fit specific productions.

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