Marble processing for future uses of $CaCO_3$-microfine dust: a study on wearing out of tools and consumable materials in stoneworking factories

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Marble processing for future uses of $CaCO_3$-microfine dust: a study on wearing out of tools and consumable materials in stoneworking factories

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Abstract

The demand for Limestone/Calcium Carbonate (LCC) has substantially grown up for the last three decades due to the widespread use of $CaCO_3$ in many industrial applications, not only in construction but also in other important sectors (e.g. environmental, food, pharmaceutical, paper, etc.). LCC is currently produced within the quarry and in processing plant (during crushing, milling, washing, etc.). In dimension stone industry almost 30 % of the block (squared or shapeless) is lost during sawing/cutting/processing. In the case of the Orosei Marble (East Sardinia, Italy), the sludge deriving from processing is mainly composed of Calcium carbonate and it has a great potential as secondary raw material or by-product as long as the chemical properties of the sludge meet the parameters required by current environmental laws. The research presented in this paper aims to explain how tools wear out and how consumables end up in the sludge.

Keywords: Calcium carbonate; stone processing; diamond tools; wear; recycling.

1 Introduction

Calcium carbonate ($CaCO_3$) is a common mineral of the earth crust everywhere in the world; it is the main component of shells of marine organisms, snails, pearls, and eggshells. Regarding its industrial applications, it is the most widely used filler. Moreover, Calcium carbonate is the active ingredient in agricultural lime. It is commonly used in medicine as a calcium supplement or as an antacid, although excessive consumption can be hazardous to health. In the past, its use was associated to a substantial cost reduction but today it is made to be used in many common products used on a daily basis (Ash and Ash, 2007). Calcium carbonate has various industrial uses including: agricultural soil amendment, manufacture of cement, filler in the manufacture of various types of paper, paint, and polypropylene, production of soda, blast furnace flux, acid neutralizer for industrial effluents and for heavy metal sorption, flue gas desulphuration in electric power stations, manufacture of lime, resin conglomerates for flooring and coating in the construction industry, it has multiple chemical applications, including cosmetics and pharmaceuticals (Careddu et al., 2009).

Product specifications for the calcium carbonate vary depending on the application (Harben, 2002). However, the most important specifications regarding Calcium carbonate for industrial uses are: $CaCO_3$ grade (purity), brightness and mean particle size.

The idea of using microfine dust from marble processing plants can match with the standards required by the market.

In detail, the polishable limestone studied in this paper (which is known by the trade name of “Orosei Marble” and it is quarried in Eastern Sardinia, Italy) is composed of around 97 % $CaCO_3$. In addition to this, its scrap (microfine dust) contained in dewatered sludge deriving from sawing/processing plants has a mean particle size of 5 microns, good brightness and has a bright whitish colouring (Careddu et al., 2014).

About 60,000 m^3 of microfine dust are generated every year in Orosei Marble producing area; this waste is currently allocated in the municipal landfill. By utilizing recycled stone waste this material is no longer regarded as a real waste but as primary or secondary raw material which can have different applications (Marras et al., 2010), with the twofold objective of minimizing the production and disposal of waste and producing added value (Siotto et al., 2008). However, it is necessary to pay close attention to waste law/regulations.

Waste is defined as something that the individual wishes to dispose of whenever it is no longer needed; the collection and treatment of waste is required by the public (OECD, 1998).

Many different concepts of waste are given in Europe. They have developed in every Member States to respond to local geographical, cultural, historical and administrative conditions. As a result, the definition of waste changes from country to country and it is sometimes difficult to translate.

The European framework directive on waste contributes to harmonize this situation but the European Commission argues that national laws still use definitions and classifications that distance themselves from the European terminology. The term “waste” has a negative image because it qualifies a material from the perspective of the upstream activity that generated it. It is, in other words, the point of view of the person who cannot use it any more. However, it does not in any way mean that recovery or recycling is excluded.

The waste resulting from the quarrying industry is classified according to potential for causing hazard to environment and most of the times can be considered as inert or non-hazardous and it is restrained within the extraction facilities. The essential feature which makes the difference is the size. Stone waste generally presents very large particle size distribution, from blocks to micronized particles (Careddu et al., 2013).

In detail, the microfine-grained residues, resulting from operations of sawing and polishing, are usually stored in landfill after the sludge water-treatment process.

In the European Waste Catalogue (EPA, 2002) code 01 is referred to as "Wastes resulting from exploration, mining, quarrying, physical and chemical treatment of minerals", with five sub-codes.

Excluding topsoil, all the others can be generally included in sub code 01 04 "Wastes from physical and chemical processing of non-metalliferous minerals" as: waste gravel and crushed rocks, dusty and powdery waste, waste from stone cutting and sawing, wastes not otherwise specified.

Being able to manage these wastes in order to prevent or minimize their adverse effect in the environment is essential for the correct functioning of the natural stone industry.

In Italy, the regulatory requirements governing the extractive industry and its products and waste are well-defined especially as far as waste materials are concerned.

Italian Legislative Decree (ILD) No. 152 of 3rd April 2006 (ILD, 2006a) concerning environmental matters is the fundamental regulation which acknowledges Article 1 (a) of the EEC Directive 75/442 that defines "waste" as *"any substance or object in the categories set out in Annex I which the holder discards or intends or is required to discard"* (ILD, 2006b).

Processing waste is classified as special waste. These by-products are coded in the European Waste Catalogue as *010413* "*waste from stone cutting and sawing other than those mentioned under item 010407*".

Article 186 of the ILD No. 152, amended by ILD. No. 4 dated January 16th 2008 (ILD, 2006a), introduces changes regarding stone processing waste, exempting this material from the regulatory requirements for waste under particular circumstances. More specifically, stone sawing and processing waste is not considered waste if it is utilized, without transformation, as envisaged in projects subject to Environmental Impact Assessment, or alternatively, if approved by the regional environmental protection agencies or any other competent authority, as long as the material as a whole does not contain contaminants exceeding current regulatory limits, as per Annex 1, col. B, of D.M. 471/99 (IMD, 1999).

Microfine carbonatic particles have been so far considered as waste and treated as such by their producers. However, the above-mentioned regulatory requirements suggest a potential value of this material and the possibility to convert it into marketable products.
A vast array of industrial sectors is currently looking for alternative raw materials; they have optimised their production chain in order to reduce the amount of waste and environmental impact. Consequently, the recycling of stone waste and by-products is demanded by the environmental laws because it fulfils the concept of sustainable development (Marras et al., 2010a).
Consequently, it is necessary to verify and study the presence of pollutants in sludge that may be linked to the wear of tools and to the overall consumption of other materials, which are used in the stoneworking process.

2 General

In more advanced factories, marble sawing and cutting is carried out with the use of diamond technologies (Wang and Clausen, 2012).
When block squaring is needed, it can be done by stationary diamond-wire installations (Primavori, 2008). Squared blocks are then sawn by gangsaws equipped with diamond-segment blades by mean of rectilinear movements and are simply water-cooled.
In case of production cycles for standard manufactures (e.g. tiles, but also strips or set-size pieces), the starting point is a shapeless and/or undersized block that is usually sawn by a block-cutter. The subsequent processing is the crosscut operation: a cut on both ends of the strip, made to even up the short sides and, whenever possible to get a size that is a multiple of its final size.
Mechanical polishing uses abrasives to smooth the workpiece surface (Xi and Zhoub, 2005). The dressing and smoothing of marble is done with five to eight Frankfurt diamond sector chucks with the help of the modern continuous-belt polishers (Primavori, 2006). Porous tools with silicon carbide and resin-based bonders (Frankfurt1 P types) are used in the pre-finishing phase, and in the finishing section, by resinoid abrasives (Frankfurt1 C types). As the smoothing process is carried out, the abrasives grains generally decrease from 20 to 1200 mesh.
Polishing heads are used in the final phase. In the case of limestone (and marbles in general), polishing is substantially a chemical process, rather than a mechanical one because there is no stone abrasion. The glossy finish is obtained by forming a film: this is not exclusively obtained by a progressive pores closure, as in the case of granites.

The number of dressing/smoothing, finishing and polishing heads varies depending on desired production (Damiani, 1993) and surface quality.

The diamond tools wear out, according to Tönshoff and Warnecke (1982) by diamond chipping and/or by smoothing, diamond pullout, embedding metal alloy wear. Ersoy et al. (2005) showed that the most common wear mechanism operating on saws during rock cutting is abrasion.

Therefore, grinding tools wear happens because of the mutual friction with the stone slab surface.

In addition, epoxy resins and flocculants are consumable materials used in marble/limestone processing.

3 Experimental

In order to have a wider knowledge of tools and consumable materials used in marble processing, tools/materials yields have been studied in three factories (here named A, B and C) whose production lines were different from each other (see both Figure 1 and Table 1).

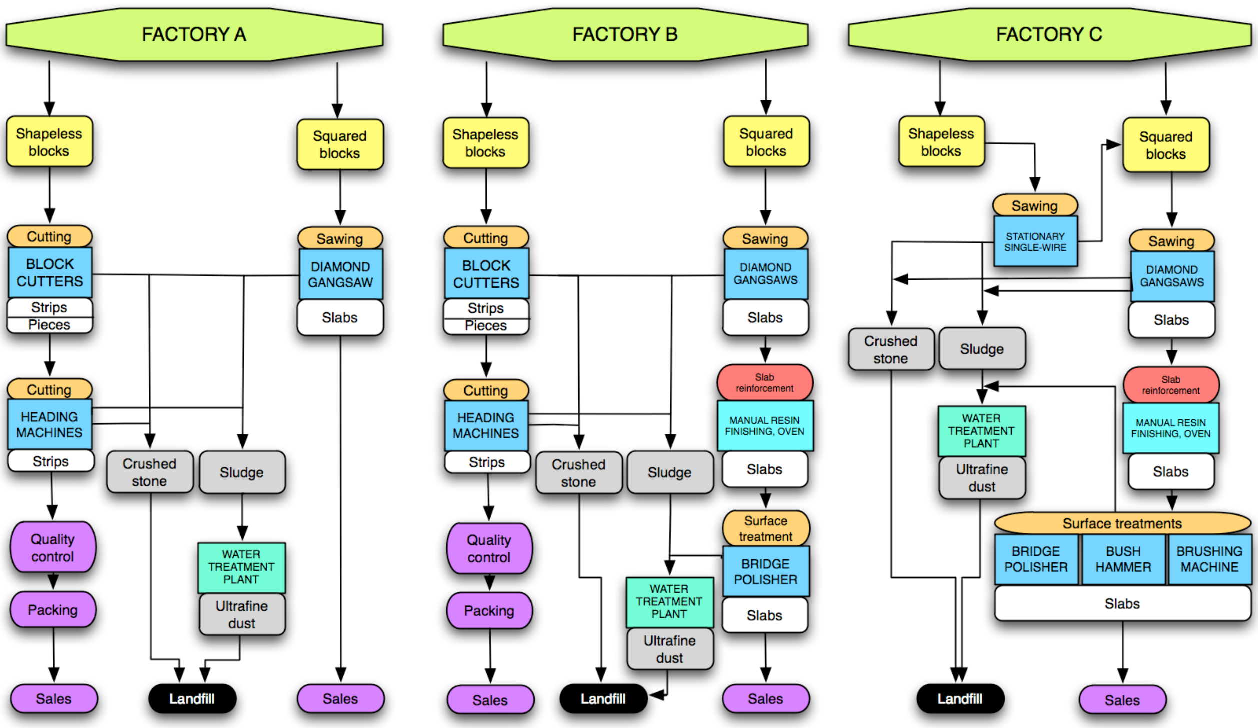


Figure 1. Factories A, B and C flowcharts.

The choice of studying three manufacturers with a different production cycle was made to verify how the pollutants content can vary depending on tools wear and on the use of consumable materials in the final sludge as production line or cycle changes.

The authors underline that Orosei Marble is the only stone which is processed in those three factories. This focus turns out to be a strategic choice: in fact, in order to carry out a serious comparison between the chemical analysis features of the stone (block, at the initial input phase) and sawing sludge sampled in the exit of filter press, the processed stone must be the same . In this direction it is certainly of great help the fact that the deposit of Orosei Marble has a highly constant chemical composition (Careddu and Siotto, 2011).
The production lines of the three factories are summarized in table 1.

Table 1. Production lines in factories A, B and C

Factory	Products	Equipments (machines number)
A	Slabs (saw-plane), strips, tiles.	Multi-blade gangsaw (1), block-cutters (4), heading machines (6), water treatment plant (1)
B	Slabs (saw-plane or polished), strips, tiles.	Multi-blade gangsaws (4), block-cutters (4), heading machines (8), resin-coating line (1), belt polishing machine (1), water treatment plant (1).
C	Slabs (saw-plane, polished or otherwise finished).	Stationary single-wire installation (1), multi-blade gangsaws (3), resin-coating line (1), belt polishing machine (1), bush-hammering/brushing line (1), water treatment plant (1).

Production in the three factories was constantly monitored for about a year, with the aim of collecting a comprehensive database of the consumption of each tool and material.
Each consumable material (including tools) used directly in the stone processing has been carefully studied in its composition, geometry and service life (yield). More precisely, the consumption of: diamond wires, diamond blades, diamond discs, resins, diamond Frankfurts, smoothing and polishing Frankfurts, and flocculants was taken into account.
This study did not take into account the wear of both bush hammers and brushes (only present in factory C) because the production of bush hammered or brushed slabs is considered irrelevant in relation to the total output.
Even the consumption of block cutters horizontal disks has not been taken into account, because their yield exceeded the year. Yields are listed in table 2.

Table 2. Tools and consumable materials yield for the factories A, B and C. Dash-line indicates the absence of that technology in the factory.

Tool/consumable material	A	B	C
Diamond wire [m^2/m]	-	-	35
Diamond blades [m^2/blade]	1,240	1,850	700
Diamond disks (block cutters, vertical) [m^2/disk]	12,512	14,490	-
Resin [g/m^2]	-	650	135
Frankfurt diamond abrasive sectors [m^2/Frankfurt]	-	150	3000
Frankfurt1 P [m^2/Frankfurt]	-	110	140
Frankfurt1 C [m^2/Frankfurt]	-	100	120
Polishers [m^2/polisher]	-	40	40

Flocculant [g/m³ dewatered sludge]	300	300	50

Some differences in the yield of tools are easily explained.

Regarding both sawing and cutting, we should notice that the equipment of factory B is more recent and therefore guarantees a better performance.

The high consumption of resin measured in factory B is related to the fact that the company extracts their blocks in a more fractured deposit area compared to the quarrying area of company C.

Despite the yield of the diamond blades used in the factory C, their gangsaws seems low, it ensures optimum slabs sawplane in terms of smoothness: this is reflected in an extremely positive smoothing process with high yield of diamond Frankfurts.

Computation of calcareous material removed from each tool was made by considering both its yield and geometrical and logistical considerations. The results concerning the computation of the micro-fine limestone daily production are consistent with the measured volumes at the filter presses output.

Figure 2 shows the main geometrical sizes of the diamond tools studied.

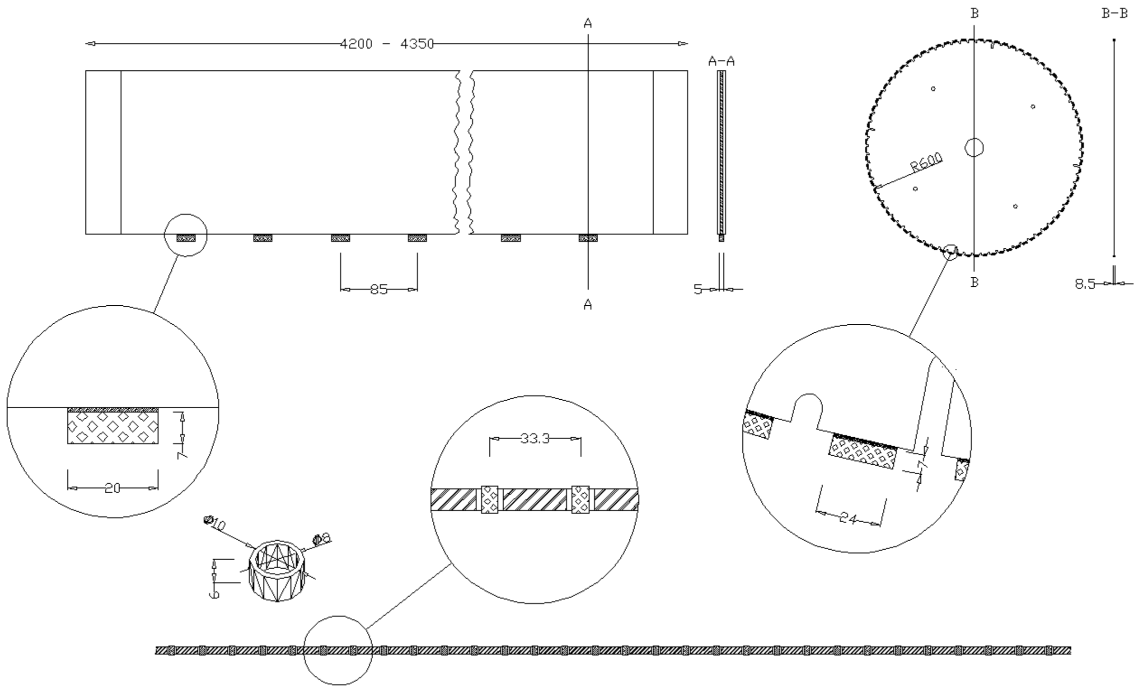


Figure 2. Geometrical sizes (given in mm) of diamond tools used in factories A, B and C.

Below is an easy-to-read explanation of how computations were carried out. It should be noted that the average measurements of squared blocks are: 3 m length, 1.6 m high, and 1.3 m width. Shapeless blocks are smaller.

The solid metal alloy, which holds the diamonds of all the diamond tools included this study, is mainly composed of bronze (30 – 50 %) and Fe-P or iron-carbonyl (Cai, 2007-2010). Cobalt is currently used in much lower percentage than in the past because of its high market price. Diamond volume in the alloy is about 2.94 %. The solid metal alloy (with diamonds) has 8.16 g/cm^3 density.

3.1 Diamond-wire.

The stationary single-wire installation uses length of diamond wire of 20.50 m. The tool is assembled with 30 beads/m, springs and plastic. The diameter of beads decreases throughout the service life of the diamond wire, from 10 to 8 mm.

This last data were taken into account in relation to the annual output of the stationary single-wire installation monitored (4,560 m^2/year).

Within one working day (8 hours) the diamond wire produces approximately 0.162 m^3 microfine limestone dusts and loses about 21.39 g diamond-metal alloy by wear.

3.2 Diamond blades

The number and length of the blades are depending on the gangsaw model. Gangsaws generally hold a number of blades so as to obtain the same number of slabs, with a thickness 3 cm and 2 cm. The gangsaws of factories B and C generally hold 44 diamond blades (having 4200 or 4350 mm length), while the gangsaw in factory A holds 28 diamond blades (4200 mm).

Gangsaws of A, B, and C factories produce an amount of micro-fine limestone dust respectively 1.056 m^3, 8.448 m^3 and 3.036 m^3 on a daily basis. The blades, on average, lose respectively 35.02 g, 187.80 g and 178.37 g diamond-metal alloy daily.

3.3 Diamond disks

These tools are used in production lines that have shapeless blocks in input (modulmarble). Each block cutters is equipped with one vertical disk (ϕ 1200 mm) and a horizontal disk (ϕ 350 mm). Strips are taken downstream after being cut and then moved to the single-disk (ϕ 350 mm) crosscutters.

Modulmarble lines produce daily an amount of micro-fine limestone dust equal to 2.428 m^3 (factory A) and 2.515 m^3 (B).

Diamond-metal alloy which was lost daily from block-cutters was respectively 41.13 g (factory A) and 35.51 g (B).

3.4 Smoothing and polishing tools

A continuous-belt polisher holding fifteen heads (more exactly: 5 smoothing, 4 pre-finishing, 4 finishing and 2 polishing heads) was monitored in factory B; a similar machine equipped with eighteen heads (6+5+4+2) was monitored in factory C. In both machines each head takes eight tools provided by the same manufacturer.

For accuracy purposes, 4 categories were identified: diamond sectors (I), pre-finishing smoothing tools (II, grain from 46 to 180 mesh), finishing smoothing tools (III, grain from 220 to 800 mesh) and polishers (IV). Within a same category, tools have same geometries and densities.

The thickness of the average amount of limestone which was removed from each smoothing head was calculated during monitoring; moreover, the following values of limestone dust were found on a daily basis: 1.4 m^3 (factory B) and 0.84 m^3 (factory C). The abrasives geometry, density and yield, as well as the productivity of the machineries were examined.

3.5 Flocculants

Anionic polymer typically offers the best flocculation performance of both settling rate and turbidity (Ersoy, 2005; Careddu and Aru, 2013) in natural carbonatic stones (such as marble, limestone and travertine) suspension.

The average daily consumption of anionic flocculant in the three factories turned out to be approximately 300 g (A and B) and 50 g (C).

3.6 Epoxy resins

As mentioned above, factories B and C are both equipped with a modern resin-coating installation for slab with the purpose to improve the slab strength.

The resins used are liquid epoxy systems consisting of two components: the resin Bisphenol A and the amino hardener; they are mixed in a ratio equal to about 1:1.

Before epoxy resin application, slab is heated to 40° C; resin then seeps into the rock by impregnation inside of fissures and cracks naturally occurring in the stone. As well explained by Primavori (2002), the following resin catalysis (its hardening or “ripening”) is speeded up by the use of ovens.

During monitoring it was noted that, on average, 50% of the resin penetrated inside the slab; the resin hardened on the slab surface is then removed during the smoothing process. However, this percentage may vary depending on the stone fissuring/fracturing state.

According to these data and calculations, the average amount of epoxy resin that daily ends in dewatered sludge is approximately 67,5 kg (B) and 40,5 kg (C).

4 Results and discussion

Results were summarized in the charts shown in Figures from 3 to 6.

The stacked columns chart in Figure 3 shows how microfine dust, stored in the accumulation point below the filter press, is composed almost exclusively of limestone scraps, with percentages that come very close to 100%. These data help to demonstrate that the dewatered sludge can be ranked as a pure and clean by-product.

This statement is also supported by the chemical analyses performed on dewatered sludge samples collected below the filter presses. The comparison between chemical analysis values of sludge with those of the same natural stone is documented in table 3. It should be noted that the presence of polluting metals (potentially resulting from the diamond-metal alloys wear) have negligible percentages and below the limits of environmental laws. Also the XRD analysis shows that the instrument detects only $CaCO_3$. For instance, Figure 7 shows the XRD spectrum of the dewatered sludge sampled in the factory B.

Table 3. Chemical analysis of Orosei marble (average) and sampled sludges.

Analyte Symbol	Unit Symbol	Detection Limit	Analysis Method	Factory A sludge	Factory B sludge	Factory C sludge	Orosei Marble (average)
SiO_2	%	0.01	FUS-ICP	0.08	0.6	< 0.01	0.18
Al_2O_3	%	0.01	FUS-ICP	0.08	0.28	0.07	0.01
Fe_2O_3(T)	%	0.01	FUS-ICP	0.04	0.12	0.03	0.01
MnO	%	0.001	FUS-ICP	0.005	0.009	0.005	0.003
MgO	%	0.01	FUS-ICP	0.46	0.52	0.45	0.40
CaO	%	0.01	FUS-ICP	54.9	53.47	53.15	54.44
Na_2O	%	0.01	FUS-ICP	0.02	0.03	0.02	0.004
K_2O	%	0.01	FUS-ICP	< 0.01	0.04	< 0.01	< 0.01
TiO_2	%	0.001	FUS-ICP	0.005	0.014	0.003	< 0.001
P_2O_5	%	0.01	FUS-ICP	0.02	0.08	0.03	0.03
LOI	%		FUS-ICP	43.82	43.86	45.13	44.78
Total	%	0.01	FUS-ICP	99.46	99.02	98.90	99.86
Sc	ppm	1	FUS-ICP	< 1	< 1	< 1	< 1
Be	ppm	1	FUS-ICP	< 1	< 1	< 1	< 1
V	ppm	5	FUS-ICP	< 5	< 5	< 5	< 5
Cr	ppm	20	FUS-MS	< 20	< 20	< 20	< 20
Co	ppm	1	FUS-MS	< 1	< 1	< 1	< 1
Ni	ppm	20	FUS-MS	< 20	< 20	< 20	< 20

Cu	ppm	10	FUS-MS	< 10	< 10	< 10	< 10
Zn	ppm	30	FUS-MS	< 30	< 30	< 30	< 30
Ga	ppm	1	FUS-MS	< 1	< 1	< 1	< 1
Ge	ppm	1	FUS-MS	< 1	< 1	< 1	< 1
As	ppm	5	FUS-MS	< 5	< 5	< 5	< 5
Rb	ppm	2	FUS-MS	< 2	< 2	< 2	< 2
Sr	ppm	2	FUS-ICP	161	177	164	170
Y	ppm	2	FUS-ICP	< 2	< 2	< 2	< 2
Zr	ppm	4	FUS-ICP	30	11	4	6
Nb	ppm	1	FUS-MS	< 1	< 1	< 1	< 1
Mo	ppm	2	FUS-MS	< 2	< 2	< 2	< 2
Ag	ppm	0.5	FUS-MS	< 0.5	< 0.5	< 0.5	< 0.5
In	ppm	0.2	FUS-MS	< 0.2	< 0.2	< 0.2	< 0.2
Sn	ppm	1	FUS-MS	< 1	< 1	< 1	< 1
Sb	ppm	0.5	FUS-MS	< 0.5	< 0.5	< 0.5	< 0.5
Cs	ppm	0.5	FUS-MS	< 0.5	< 0.5	< 0.5	< 0.5
Ba	ppm	3	FUS-ICP	13	17	16	10
La	ppm	0.1	FUS-MS	1.2	1	0.3	0.6
Ce	ppm	0.1	FUS-MS	1.9	1.5	0.3	0.8
Pr	ppm	0.05	FUS-MS	0.18	0.18	< 0.05	0.9
Nd	ppm	0.1	FUS-MS	0.6	0.7	0.2	0.3
Sm	ppm	0.1	FUS-MS	< 0.1	0.1	< 0.1	< 0.1
Eu	ppm	0.05	FUS-MS	< 0.05	< 0.05	< 0.05	< 0.05
Gd	ppm	0.1	FUS-MS	< 0.1	0.2	< 0.1	< 0.1
Tb	ppm	0.1	FUS-MS	< 0.1	< 0.1	< 0.1	< 0.1
Dy	ppm	0.1	FUS-MS	< 0.1	0.1	0.1	< 0.1
Ho	ppm	0.1	FUS-MS	< 0.1	< 0.1	< 0.1	< 0.1
Er	ppm	0.1	FUS-MS	< 0.1	< 0.1	< 0.1	< 0.1
Tm	ppm	0.05	FUS-MS	< 0.05	< 0.05	< 0.05	< 0.05
Yb	ppm	0.1	FUS-MS	< 0.1	< 0.1	< 0.1	< 0.1
Lu	ppm	0.04	FUS-MS	< 0.04	< 0.04	< 0.04	< 0.04
Hf	ppm	0.2	FUS-MS	< 0.2	< 0.2	< 0.2	< 0.2
Ta	ppm	0.1	FUS-MS	< 0.1	< 0.1	< 0.1	< 0.1
W	ppm	1	FUS-MS	< 1	< 1	< 1	< 1
Tl	ppm	0.1	FUS-MS	< 0.1	< 0.1	< 0.1	< 0.1
Pb	ppm	5	FUS-MS	< 5	< 5	< 5	< 5
Bi	ppm	0.4	FUS-MS	< 0.4	< 0.4	< 0.4	< 0.4
Th	ppm	0.1	FUS-MS	< 0.1	0.3	< 0.1	< 0.1
U	ppm	0.1	FUS-MS	0.2	0.4	0.3	0.2

Pie charts in Figures 4, 5 and 6 show how what was left from both the wear of tools and the others consumable materials is divided in the sludges of the factories A, B and C.

It is noticeable how in factory A the diamond-metal alloy consumption (both from the four modulmarble lines and from the one gangsaw wear) is clearly lower than the consumption of flocculant (Figure 4). Another key result is that in the factory equipped with only diamond technologies (i.e. it means without polishing line) the substances ending in dewatered sludge are virtually null as shown in the column A of Figure 3. Indeed, the two other pie charts

(Figures 5 and 6) show that the higher percentage of consumable materials found in the dewatered sludge is linked to the epoxy resin removal from the slabs (about 80 %). A more substantial portion, in both cases more than 12 %, is linked to the usage of polishers.
Finally, despite the widespread use of diamond technologies, the dewatered sludges coming from factories B and C have almost insignificant percentages of diamond-metal alloy.
This suggests that in order to improve the $CaCO_3$ quality for the market, it is necessary to intercept the sewage lines when they are just out of the sawing/cutting sections to collect sludge separately. This by-product (which of course is no longer a waste) is believed to have far better standards for industrial products such as paints, rubber, paper, etc.
However, the presence of material consumption linked to resins and smoothing/polishing tools in dewatered sludge, does not seem to pollute the product itself from a chemical point of view; the ongoing study indicates a slight variation in colour of dry mud.

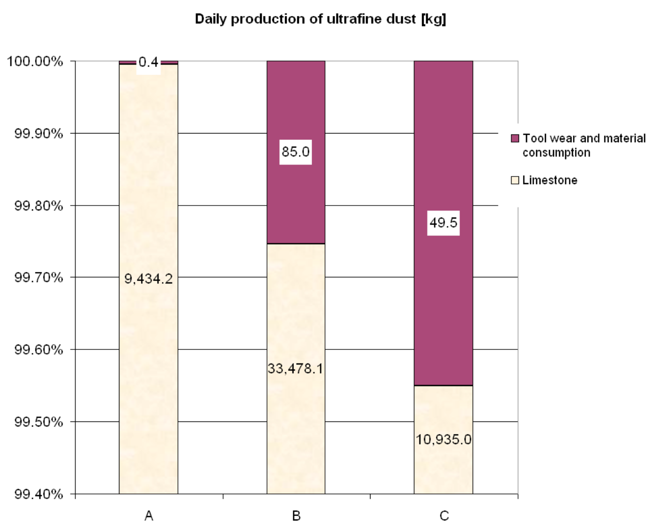
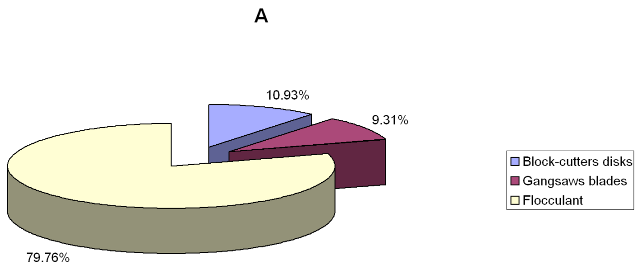
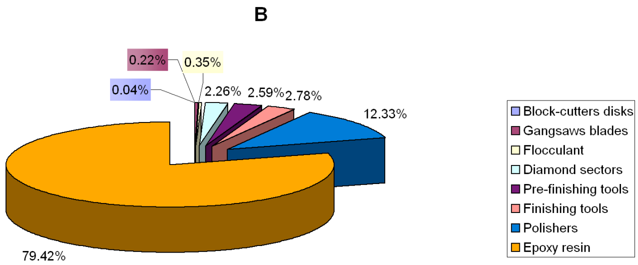
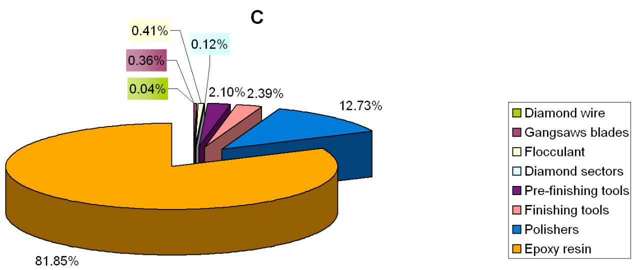


Figure 3. Daily production of microfine dust.







Figures 4, 5 and 6. Percentage distribution of microfine dust (in factories A, B and C respectively) deriving exclusively from tools and materials consumption that ends in 1 m^3 of dewatered sludge.

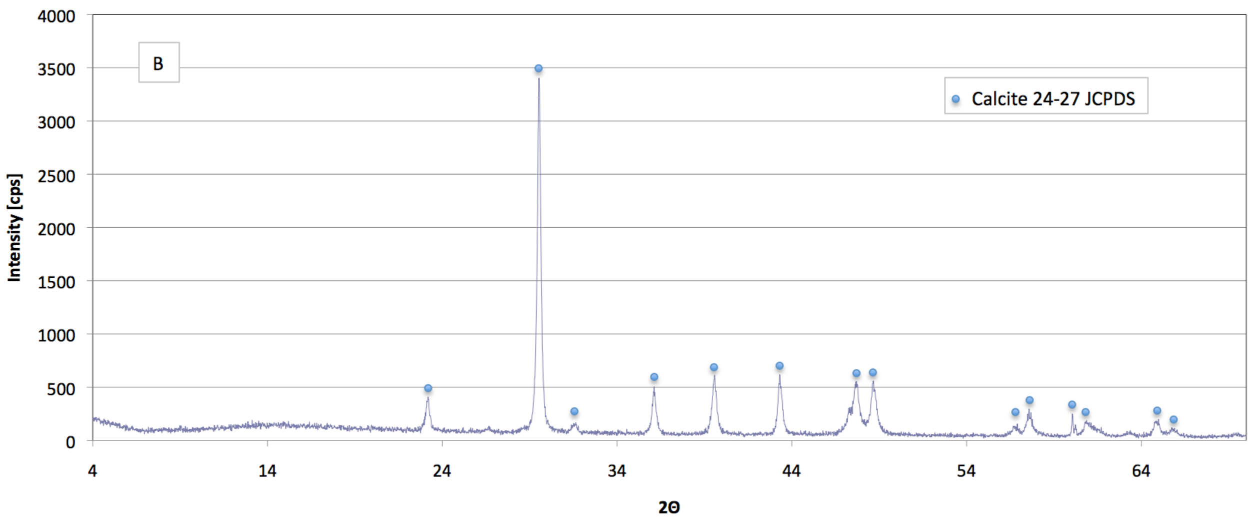


Figure 7. Mineralogical spectrum of sludge produced in factory B.

5 Conclusions

Research on yields of tools and consumable materials in marble/limestone processing and their impact on the final sludge is very difficult due to the high yield of the same tools. However, the following results can be stressed:

- from the point of view of both chemical analysis and computations, microfine dust produced in Orosei Marble district has excellent $CaCO_3$ features (regarding grade and mean particles size);
- dewatered sludges are almost entirely made of limestone (from the input natural stone);
- the main percentage of consumable material included in the sludge is linked to epoxy resin and polishers;
- the percentage of diamond-metal alloy in the sludge is negligible.

Things are different in the case of tools used in granite processing, where their yields are significantly lower due to high abrasiveness of the stone (Amaral et al., 2009). In fact, in granite processing, a higher percentage of pollutant metals could be detected, possibly due to a higher wearing out of the tools. Moreover, partly due to environmental laws, the reuse of sludge produced in granite processing has not encouraged a widespread use of industrial applications which are indeed possible which the limestone dust.

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