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Characterization of Dimension Stone Sawing Sludge in Egypt

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Abstract: The aim of the present study is to determine the mineralogical and chemical characteristics of dimension stone sawing sludge in Egypt. Particle size, XRD, SEM and XRF analysis were carried out on representative samples of marble (limestone) and granite sludge. The marble sludge was found to mainly compose of calcium carbonate whereas the granite sludge varies in composition according to the mineralogy of the parent stone processed. The mineralogical and chemical characteristics of the dimension stone sludge are important factors in the determination of the most appropriate recycling options of this waste into different applications.

Key words: Dimension stone, granite, marble, recycling, sawing sludge

INTRODUCTION

According to ASTM C-119 standard terminology, dimension stone is natural stone that has been selected and fabricated to specific sizes or shapes with or without one or more mechanically dressed or finished surfaces for use as building facing, curbing, paving stone, monuments, memorials and various industrial products. The two most common groups of dimension stone are the granite group and limestone group. The granite group, as commercially defined is composed of a visibly granular, igneous rock generally ranging in colour from pink to light or dark grey and consisting mostly of quartz and feldspars, accompanied by one or more dark minerals. The texture is typically homogeneous but may be gneissic or porphyritic. Some dark granular igneous rocks though not geologically granite, are included in the definition. The limestone group, on the other hand is composed of a rock of sedimentary origin composed principally of calcium carbonate (calcite) with varying amounts of dolomite. Re-crystallized limestone, compact microcrystalline limestone and travertine that are capable of taking a polish are marketed as limestone or more commonly as “marble”. From the geological point of view, marble is however, a metamorphosed carbonate rock (ASTM C-119, 2008).

The quarried dimension stone blocks are either exported as raw blocks or transported to processing factories where they are trimmed and then cut mainly by gang saws into slabs 20 mm thick or thicker according to demand. The plates are then subjected to further processing (brushing, polishing, treatment with resin, seizing…etc). The process of cutting, shaping and finishing of dimension stone belongs to industry ISIC Class 2396 (United Nations, 2008), to differentiate it from dimension stone quarrying (ISIC Class 0810). The processing of dimension stone into slabs requires a minimum block volume, which has been defined as follows: Length$\geq$1 m, width$\geq$1 m and thickness$\geq$0.4 m (Singewald, 1992).

Dimension stone sludge (referred to as marble sludge, granite sludge or slurry) is generated as a by-product during the sawing of the stone blocks. In this process, water is used as a coolant and the powdered rock produced as a result of the friction and movement of the saw blade within the block is removed with the cooling water. Some factories use additives like slaked lime and iron powder to act as abrasives and lubricants to facilitate the sawing process (especially of granitic blocks) and to extend the life of the saw blade. These powders are also removed with the rock powder into the sludge. The amount of water used for cooling varies markedly from one factory to another according to the number, size and type of blocks sawn per year (granitic blocks require more water than limestone blocks) and to the water re-cycling efforts of the factory. In some factories, the dimension stone slurry is discharged into settling tanks or ponds; the supernatant water is removed into storage tanks for reuse as coolant water. The settled sludge (with up to 50% water content) is removed and transported for disposal on land or in landfills. In other factories, the use of a filter press has decreased the water content of the sludge to about 20%, thereby recovering more water for recycling and generating more quantities of rock powder in the form of coherent cake that is easier to transport to the disposal sites. The amount of dimension stone sludge

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produced in the sawing process varies according to the texture and hardness of the stone, the size of the slabs to be produced and the thickness of the saw blade. In general, it is estimated that about 20% of the total weight of the stone block is converted into slurry (Singewald, 1992; Torres *et al*., 2009).

The sludge generated during the processing of stone blocks has hitherto, no specific practical applications and has been managed as waste. However, the business conscience of recycling has stimulated both small and big enterprises to look for alternative solutions aiming at recycling and adding commercial value to the final products taking into consideration environmental legislations. Accordingly, several studies have been carried out to investigate different possibilities for using dimension stone sludge for different purposes (Torres *et al*., 2004, 2007, 2009; Segadaes *et al*., 2005; Acchar *et al*., 2006; Almeida *et al*., 2007; Karasahin and Terzi, 2007; Nour *et al*., 2008; Ibrahim *et al*., 2008; Montero *et al*., 2009a, b; Aruntas *et al*., 2010).

The aim of the present study is to describe the different textural, mineralogical and chemical characteristics of dimension stone sawing sludge produced in Egypt and to outline different opportunities for recycling this sludge for different purposes.

MATERIALS AND METHODS

Dimension stone (granite and limestone groups) has been exploited in Egypt since ancient Egyptian times (Klemm and Klemm, 2008) for details on the use of stones in Ancient Egypt). The dimension stone industry in Egypt has grown steadily since the year 2000. According to a study by IMC (2005), the production of dimension stone in Egypt amounted to 3.2 million tones in 2004, with a total turnover of about 390 million US dollars (58.7% from export and 41.3% from domestic sale). According to the same study, 28% of the quarried material was exported as raw blocks whereas 72% were processed in different factories in Egypt. Of the processed blocks, 18.7% were exported as slabs and other finished products, 21.0% were marketed locally and the remaining 32.3% were discarded as waste material. On the other hand, Fig. 1 shows the production of raw dimension stone in Egypt as given by the statistics of Internazionale Marmi e Macchine Carrara SpA www. immcarrara.com/).

The quarried blocks from the Eastern Desert, Sinai and the Nile Valley are transported to factories for processing especially to Shaq Al Thobaan, a dimension stone processing industrial estate south east of Cairo near Maadi. Other processing facilities are scattered in the cities of Cairo. The sludge produced is disposed of in desert areas near the factories, particular in Shaq Al Thobaan, either on land or in nearby desert Wadis . When the sludge becomes dry (under the sunny hot weather conditions prevailing in Egypt) its fine particles become ready for transport, even by mild winds, causing significant air pollution in neighboring areas.

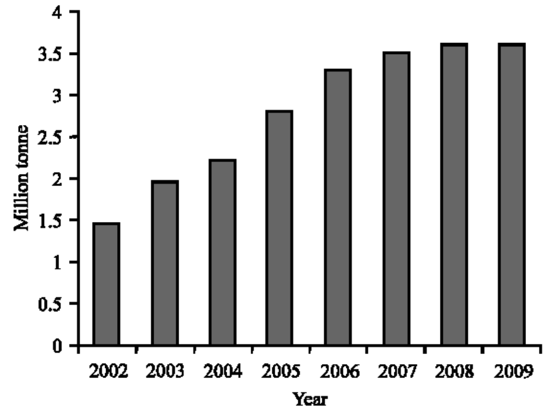

Fig. 1: Production of dimension stone in Egypt. Drawn from statistical Data given by Internazionale Marmi e Macchine Carrara SpA

Twenty samples of dimension stone sludge (10 from cutting granitic blocks and 10 from cutting limestone blocks) were collected from 10 factories in Cairo. The Shaq Al Thobaan area is located south of Cairo to the east of Maadi District and is the main dimension stone processing centre in Egypt. In this area, about 350 main factories are involved in sawing and processing of marble and granite slabs. As mentioned above, the blocks of raw material are brought by heavy trucks from scattered quarries in the Eastern Desert, Nile Valley and Sinai. Other isolated factories are located in Cairo city proper and the new city of west of Cairo. The collected samples were dried at 100°C and then gently disaggregated by rubber pestel. After quartering each sample, a portion was used for particle size analysis by wet sieving and Andreason pipette sedimentation method. A second portion was analyzed by X-ray diffraction using CuKα radiation at a scanning speed of 2α degrees/ minute in the range of 2α 4 to 70°C. A third portion of the sample was chemically analyzed by X-ray fluorescence spectrometry. And the fourth portion was examined by scanning electron microscopy.

RESULTS AND DISCUSSION

Particle size distribution and shape analysis: Table 1 gives the average particle size distribution of marble and granite sludge samples. Table 1 indicates that in both

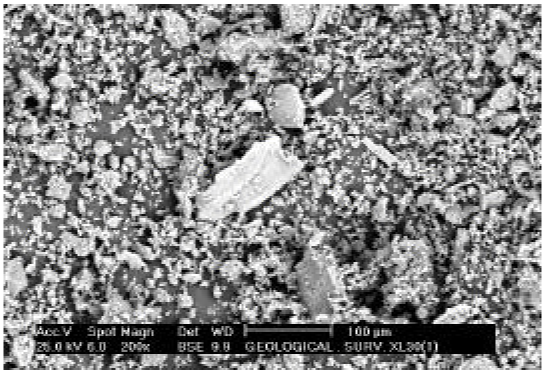

Fig. 2: BS Scanning Electron Micrograph of granite sludge particles

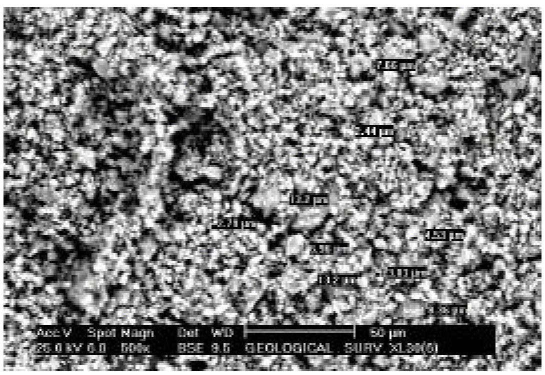

Fig. 3: BS Scanning Electron Micrograph of marble sludge particles

Table 1: Particle size distribution

Size range (microns)	Average % in marble sludge	Average % in granite sludge
125-62	0	10
62-31	2	10
31-16	35	45
16-8	25	15
8-4	24	10
4-2	5	8
<2	9	2
Mean size	13	28

cases the particle size distribution is multidimensional, i.e., consisting of two to three populations. The 2marble sludge samples are finer than the granite ones and 23 are mainly composed of particles between 31 and 4 microns, with a mean size of 13 microns. On the other hand, the granite sludge is mainly composed of particles between 125 and 16 microns, with a mean size of 28 microns.

Scanning electron micrographs show that the particles of the granite sludge are predominantly poorly sorted (Fig. 2), whereas the particles of the marble sludge are better sorted and finer (Fig. 3). Both particles of the

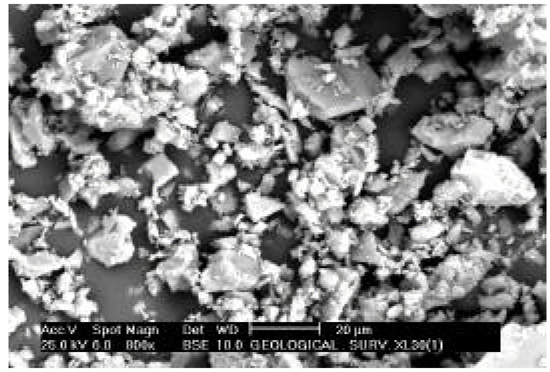

Fig. 4: BS Scanning Electron Micrograph showing the angularity of the particles of granite sludge. On the right side small crystals of feldspars were separated from the coarse-grained granite during sawing

granite and marble sludge are angular to very angular. Figure 4 shows also some well developed crystals separated from the coarse-grained granite during the cutting process. These crystals were identified as feldspar crystals.

The determination of the shape of the particles of the sludge is important in the assessment of its recycling for some purposes. For example, marble sludge can be used as a good scouring material alone or in combination with detergents. The hardness of calcite is 3 and the more angular the particles are, the more will be its scouring (abrasive) power.

Mineralogical composition: Establishing the mineralogical composition allows one to define the relative quantity of various crystalline substances present in the dimension stone sludge samples. In this case, these are essentially the minerals which make up the stone being processed. In this way it is possible to determine and quantify those minerals present and to evaluate how these would vary both in time and from one factory to another. This is important in some fields of application sludge such as in ceramics. XRD analysis carried out on the marble sludge samples showed that most samples are composed mainly of calcite (over 98% calcite) (Fig. 5). Some samples showed minor quartz and dolomite reflections (both minor minerals did not exceed 5% in the samples). In contrast, the XRD patterns of the granite sludge samples are more complex due to the presence of several crystalline minerals. The XRD patterns showed the presence of quartz, albite (sodium feldspar) and microcline (potash feldspar) as the main constituents (Fig. 6).

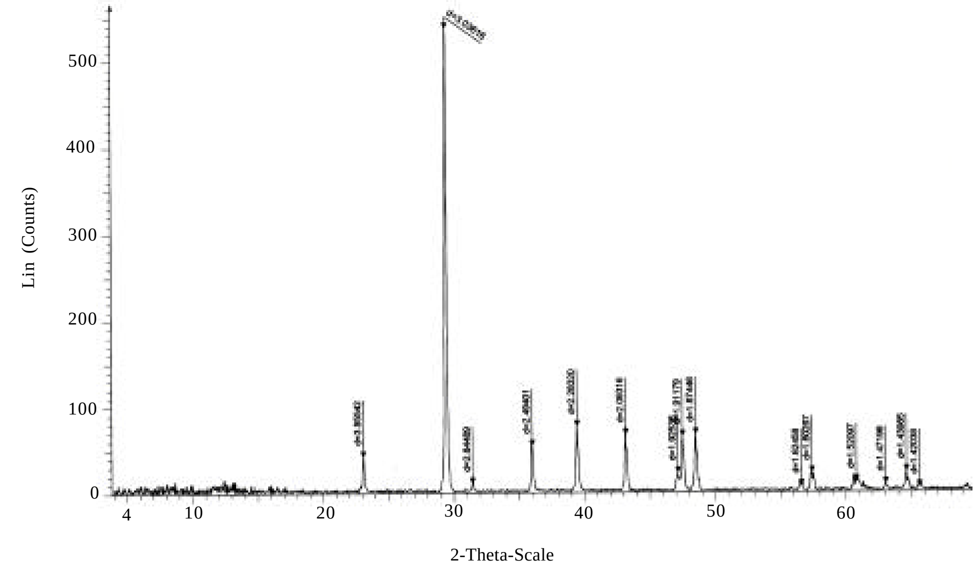

Fig. 5: XRD diagram of marble sludge showing mainly the calcite reflections

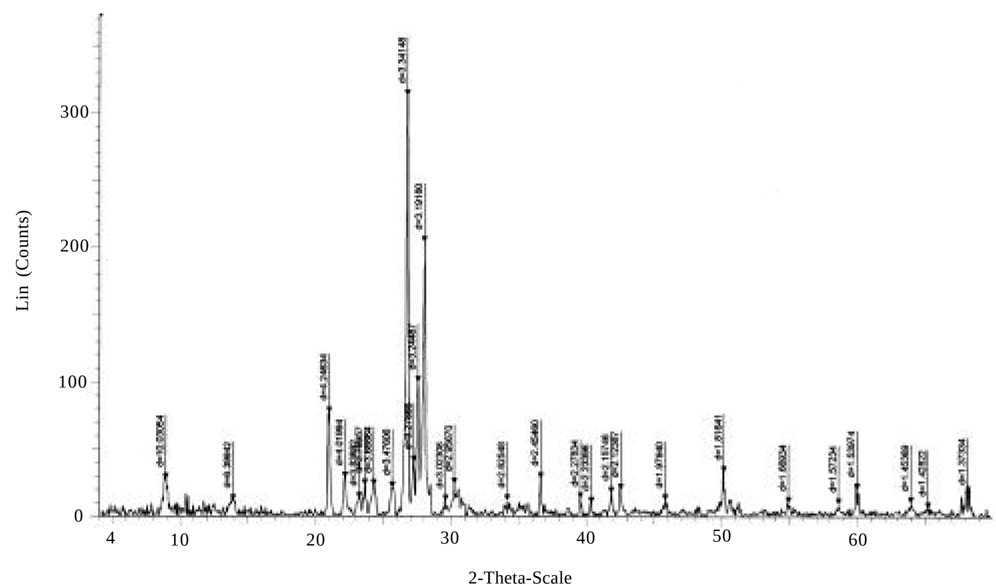

Fig. 6: XRD diagram of granite sludge showing reflections of quartz, albite Microcline and illite (alteration of feldspar)

Chemical composition: Table 2 gives the chemical composition of marble (limestone) sludge, from which it appears that it is mainly composed of calcium carbonate with varying amounts of magnesium carbonate ranging between 2.10 and 5.06%, depending on the degree of dolomitization of the parent stone block. The acid-insoluble fraction varies between 0.50 and 4.60% and is exclusively composed of fine minor quartz and clay minerals present in the rock. In general, the iron oxides are low, although some blocks show visible spots or patches of iron oxides. These are mainly present along minor cracks or in small vugs and are due to late diagenetic processes that affected the parent carbonate rock. For good quality slabs, these iron oxide patches are undesirable and if they are abundant, the slab is generally discarded as waste. As for potassium and sodium, the former is mainly present associated with the clay fraction present whereas sodium is present both in the clay

Table 2: Chemical composition of marble sludge

	1	2	3	4	5	6	7	8	9	10
SiO_2	0.32	2.94	0.90	2.00	0.64	0.64	0.38	0.64	0.59	1.60
Al_2O_3	0.10	0.90	0.43	0.61	0.20	0.02	0.12	0.20	0.10	0.49
Fe_2O_3	0.04	0.43	0.70	0.23	0.07	0.06	0.04	0.06	0.06	0.07
MgO	1.41	1.31	1.41	1.67	1.01	1.41	2.31	1.60	1.41	1.00
CaO	54.11	51.86	53.55	52.43	54.67	54.67	53.27	54.39	54.11	53.28
Na_2O	0.01	0.06	0.03	0.04	0.01	0.01	0.01	0.01	0.01	0.03
K_2O	0.02	0.18	0.08	0.12	0.03	0.01	0.02	0.03	0.04	0.10
LOI	44.03	42.50	43.60	43.00	44.01	44.47	44.47	44.48	44.03	42.93
Total	100.04	100.18	100.20	100.10	100.67	101.49	100.65	101.37	100.37	99.50
$CaCO_3$	96.59	92.59	95.59	93.59	97.59	97.59	95.09	97.09	96.59	95.10
$MgCO_3$	2.95	3.38	2.95	3.50	2.12	2.95	5.06	3.88	2.95	2.10
AIR	0.50	4.60	2.21	3.12	1.00	1.00	0.60	1.00	0.93	2.50

Samples (trade name): 1: Menia; 2: Imperial Gold; 3: Imperial biege; 4: Filetto khtmia; 5: Sylvia' 6: Galala vream; 7: Sunny; 8: Galala classic; 9: Sunny light; 10: Sunny hassana

Table 3: Chemical composition of granite sludge

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	69.37	71.44	68.22	72.23	75.33	70.39	61.05	72.13	68.57	69.32	73.18
Al_2O_3	14.44	13.60	13.76	13.95	13.60	14.95	13.26	15.71	14.85	13.33	13.72
Fe_2O_3	2.64	2.70	4.46	2.02	0.68	2.23	8.56	0.02	3.38	3.99	2.18
MnO	0.05	0.06	0.07	0.05	0.04	0.06	0.13	0.01	0.12	0.14	0.05
MgO	0.64	0.53	0.82	0.49	0.03	0.98	1.86	0.03	0.13	0.41	0.46
CaO	1.51	1.27	2.21	1.42	0.61	2.59	4.85	0.35	0.43	0.57	1.19
Na_2O	3.26	3.07	2.99	3.34	3.75	4.13	2.99	3.04	6.34	5.68	3.84
K_2O	5.74	5.49	5.07	4.53	4.65	2.92	3.76	7.73	4.76	4.78	4.28
P_2O_5	0.10	0.10	0.16	0.06	0.01	0.09	0.84	0.01	0.03	0.04	0.11
TiO_2	0.37	0.31	0.63	0.24	0.05	0.34	1.56	0.01	0.25	0.41	0.22
LOI	1.15	1.18	1.30	1.30	0.77	0.92	0.95	0.74	0.75	0.97	
Total	99.27	99.75	99.69	99.63	99.51	99.60	99.81	99.83	99.65	99.64	99.23

Samples (trade name) : 1: Aewan Light-Red; 2: Rosa Granite Sinai; 3: Red Aswan; 4: Rosa Hudi; 5: Imperial Red; 6: White Safaga; 7: Nero Aswan; 8: Halayeb White; 9: Ghazal Light; 10: Ghazal Dark: 11: Average of 459 Egyptian granites (Ali and Mostafa,1984)

fraction and as sodium chloride. The latter, which is of late diagenetic origin, may be present in marked concentration in some of the stone blocks. Slabs cut from these blocks are generally treated to prevent possible efflorescence of salt on their surface. In general, the composition of the marble sludge indicates that it can be used in a number of applications without prior treatment.

Table 3 gives the chemical composition of granite sludge as compared to the average chemical composition of Egyptian granites. The variation in composition between the samples reflects the variations in their mineralogy. For example, sample No. 7 (Nero Aswan sludge) has the highest iron content because the parent rock is richer in biotite and other ferro-magnesian minerals than the other samples. Sample No. 8 and 9 have higher alkali content because their parent rocks are richer in feldspars than the other samples.

It should be noted that the chemical composition of dimension stone sludge might differ from one factory to another. This is particularly the case if a factory discharges the sludge generated from sawing different types of blocks (e.g., a marble block and a granite block) into the same settling tank, or pond. In this case the composition of the sludge will be not be representative of either block. Such mixed composition might complicate the recycling of the sludge for some purposes. Factories should be aware of this and of the fact that optimum recycling options depend on the separation between sludge generated from the main types of stone blocks.

Several options exist for the use of both marble and granite sludge especially in the building and ceramic sectors. Almeida *et al*. (2007) and Aruntas *et al*. (2010) indicated that there is technical feasibility to incorporate quantities of marble sludge as raw material in the production of clinker, without any previous treatment. Hunger and Brouwers (2008) and Corinaldesi *et al.* (2010) studied the use of marble sludge as additive for mortars and concrete, especially for self-compacting concrete. Dhanapandian and Gnanvel (2009) examined the incorporation of granite and marble wastes with clays for the production of bricks. Karasahin and Terzi (2007) demonstrated that marble powder could be used as filler material in asphalt mixtures. Torres *et al*. (2004) studied the feasibility of using granite sludge in industrial porcelain tile formulations. Vierira *et al*. (2004) concluded that the incorporation of granite sludge up to 40% in a clay body forred ceramics is technically feasible.

Menezes *et al*. (2005) demonstrated the use of granite sludge in the production of ceramic bricks and tiles. The former are only examples of recent research directed at the recycling of sludge generating during the sawing of dimension stone. Other opportunities do exist. Production of quick lime, slake lime and precipitated calcium carbonate from marble sludge are practiced in India and China. Micro-grinding of marble sludge to produce nano-sized calcium carbonate for use as filler in plastics, paper and paint industry, etc., is a growing undetaking in China.

From the present study, it is concluded that the mineralogical and chemical characterization of the marble and granite sludge is essential to determine the appropriate recycling option(s) for these wastes. This will not only constitute an added value to the stone industry but will also lead to environmentally-sound management of their undesirable residues. The importance of prior characterization of marble and granite sludge for different applications, in particular in ceramics, bricks and concrete manufacturing has already been stressed by the above-mentioned authors. This constitutes an important factor in the design of appropriate mixes (e.g., with clay, silica fumes, aggregates, etc) for the processing of the required products.

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