Incorporation of Marble Sludge in Industrial Building Eco-blocks or Cement Bricks Formulation

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ABSTRACT

Producing eco-blocks to be used in houses' building from marble sludge through maximum possible substitution of sludge for sand and other components of the mixed materials used in block manufacturing was investigated.

Samples of different formulations, in the form of extruded bars, were produced at both laboratory and pilot-plant scales and characterized at the final stage of the production process. 178 formulations were prepared to examine the proper formulation that fits national and international standards. Just five of them were promising and two were chosen for commentary purposes.

The main objective of this study was to investigate the possibility of marble sludge recycling in the use in useful materials such as house building materials. The other objectives can be summarized in saving natural resources and reducing their used quantity. The experimental results and their theoretical interpretation show that suitable incorporation of marble sludge can result in building blocks of 15 cm with superior properties in terms of water absorption (7%). The compressive strength at age of 28 days only reached (195.8 kN or 7.8 N/mm^2).

KEYWORDS: Eco-construction blocks, Marble sludge, Natural resources, Sustainability, Environment, Waste re-use .

INTRODUCTION

Marble cutting industry produces large amounts of solid wastes on large areas, which are expected to increase as construction is continuously increased, owing to the fact that the world production of marble industry has been increasing annually in the recent years. This work reports the use of sludge generated from natural marble manufacturing processes as raw material or as a by – product instead of being a waste material. All natural stones including marble, granite and slate, which can be cut to sizes, polished and used for construction purposes, are referred to as dimensional . Dimensional stones are characterized by aesthetics/acoustics and practicality in use. Marble is a crystalline, compact variety of metamorphosed limestone, consisting primarily of calcite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$) or a combination of both minerals.

Pure calcite is white, but mineral impurities add color in variegated patterns. Marble is a durable stone in dry atmosphere only when protected from rain. The surface of marble crumbles readily when exposed to moist or acidic environment. There are two types of by-products of marble processing. During marble processing, 30% of the stone (in case of unprocessed stone) goes to scrap because of being in smaller size and/or irregular shape. This is then sold to chip manufacturers. In case of semi-

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processed slab, the scrap level reduces to 2-5%. The other waste material is slurry. It is basically the water containing marble powder.

The water is reused till it gets thick enough (70% water – 30% marble powder) to be insoluble for marble powder. It can be safely estimated that 1 ton of marble stone processed in Gang-Saw or a vertical/horizontal cutter produces almost 1 ton of slurry (70% water). As an industrial concept and for natural resources sustainable development, waste might be used as by- product in some other industry, and the by – product of one industry may be used as raw material for other industry. The use of industrial waste materials as alternatives, and sometimes as additives, in the construction and manufacture of ceramic industry (Ferreira et al., 2003) and their products have been attracting an increasing interest of researchers in recent years and is becoming common practice, especially from ecological point of view as a trend aiming at limiting the use of natural raw materials in the field of building materials (Colangelo et al., 2004).

The use of marble dust collected during the shaping process of marble in asphalt mixtures as filler material can be considered as alternative filler material (Karasahin and Terzi, 2004). Puzinauskas (1983) and Terzi (2000) have investigated the use of marble sludge in mixture as filler material in asphalt manufacture. Other investigators use marble sludge in metal contaminated soil remediation as toxicological evaluation aspect, in that marble sludge added to heavy metal polluted sediment produces a decrease of available metal forms (Perez-Sirvent et al., 2007). Therefore, detrimental effects of cement and concrete industry to the environment can be reduced (Mehta, 2001 and 2002), as well as marble industry. The marble manufacturing industries are dumping the marble waste in any nearby pit or vacant space near their unit although notified areas have been marked for dumping all over municipalities. This indeed leads to increase environmental risks as dust pollution spreads alongside for a large area especially after the slurry dries up, and to the occupation of vast areas of land, mainly agricultural lands or nearby occupied lands. In addition, the deposition of such generated huge amounts of marble wastes certainly will create necrotic ecological conditions for flora and fauna changing landscape and habitats. This also contaminates the surface and underground water reserves.

The wastes of this industrial activity can reach even 20 wt.% of the raw marble (Fernandes et al., 2003). The high daily-produced amounts and the difficulties in reducing their volume by suitable methods, require high management costs as transportation costs for their disposal on open lands or dumps. Marble blocks are cut by gang saws; water is used as a coolant. The blocks are cut in 20 mm thick sheets. Therefore, out of every 25mm thickness of marble block, 5mm are converted into powder while cutting as 20% of marble blocks are lost. This powder flows along with the water as marble slurry or marble sludge. The marble slurry has nearly 35%-45% water content. This work aims at studying the recycling potential of a non-toxic sludge generated from natural marble manufacturing processes in the preparation of innovative concrete as building material with regards to the following environmental and economical aspects:

(a) Reducing the environmental impact produced from marble manufacturing as waste and the management cost of waste produced.
(b) Producing suitable building materials that have their characteristics with regards to the adopted or active standards without any municipal risk.
(c) Maximizing the use of natural resources in industry.

As there is no ISO-standard for the building blocks or slabs, which would more interest the present work, the produced materials were evaluated in the light of the Jordanian standard adopted by the Royal Scientific Society in Jordan, which is directed to the building blocks made by dry- sand powder and sand gravel pressing, whereby water absorption must be less than 8% and compression pressure not less than 3 N/mm at 28 days for 15-cm blocks. The present work aims at studying the recycling ability of a non-toxic sludge generated from natural granite cutting processes.

The high daily-produced amounts and the difficulties in reducing their volume by suitable filter-pressing methods, require high transportation costs for disposal. This invention relates to a method for manufacturing artificial building blocks or an aggregate having a good compression strength as well as a good transverse pressure using raw marble sludge. According to the invention, raw sewage sludge and water-free waste are mixed into a blend having a water content that allows the optimal extrusion with medium-sized and coarse limestone gravels.

MATERIALS

- Marble sludge.
- Sieve of 1-2 mm openings.
- Half volume of limestone gravel of (3-5 mm) in diameter.
- Two volumes of (6-9 mm) limestone gravel.
- Agitator blender.
- Templates or mould matrix.

EXPERIMENTAL PROCEDURE

This invention relates to a method for manufacturing artificial building blocks or an aggregate, using raw marble sludge. According to the invention, raw marble sludge and water-free waste are mixed into a blend having a water content that allows optimal extrusion, whereby excellent building blocks or aggregate with low water absorption rate and low slump loss can be produced. In addition, the collective treatment of waste and the mass production of recycled products are possible without addition of a drying process for raw marble sludge, and thus excellent building blocks or aggregate can be obtained.

Table (1): A typical chemical analysis of marble slurry.

Test carried out	Test value %
Loss on ignition.	43.46
Silica	1.69
Alumina	1.04
Iron Oxide	0.21
Lime	49.07
Magnesia	4.47

Samples of different formulations, in the form of extruded bars or briquettes, were produced at both laboratory and pilot-plant scales and characterized at the final stage of the production process. Table (1) gives the average chemical composition of the dried sludge, confirming its silicious character. It contains aluminium, iron oxide, lime, magnesia and in minor quantities, less than 0.1 % soda and potash. Tables (2) and 3 show the physical characteristics of marble sludge as powder to have 1.4 gm/cc as bulk density and 2.85 as specific gravity; while particle size distribution was less than 363.5 micron and 90% of the particles were above 193 mm in size.

Table (2): Physical properties of marble slurry.

Property	Result
Bulk Density (gm/cc)	1.3-1.5
Specific Gravity	2.83-2.87

Table (3): Particle size distribution of marble slurry.

Particle size (mm)	% Finer by volume
363.1	100
193.0 – 205.8	90

The experimental procedure was as follows. The as-received marble sludge from factories was air dried and then broken to aggregates or dis-agglomerated in a hammer-mill to get fine powders. The air dried sludge was mixed with water in order to make vibratory sieving possible. Using 1-2 mm sieve, fine particles were produced in a homogeneous volume, and then a certain volume of this powder was mixed with another volume of limestone gravels of (3-5 mm) in diameter and other volumes of (6-12 mm) limestone gravels, all are blended with one kilogram black cement for each block. The mixtures were homogenized by the addition of water, and dis-agglomerated by a gently rotary machine with mechanical agitation to form the homogeneous mixture, and finally this mixture was cast to form blocks as formulated in Table (4). After natural strengthening and after removal, watering takes place on the next day, and after drying these blocks were soaked in water for 24 hours and then removed for air drying. On the next day, they are again soaked for 48 hours waiting for shipment and use.

RESULTS AND DISCUSSION

This work is actually directed to the field of designing new wall building blocks (Figure 1), dimensional compositions (Figure 2) which can meet Jordanian market requirements as well as global sustainable environment and everlasting the natural resources all over the world. Among the wide commercial and traditional concretes, building blocks must satisfy the highest and most strict quality standards, which apparently depend on the high quality of the raw materials and the optimization of the processing parameters.

Figure (1): **Produced 15 cm building blocks.**

This is, however, a difficult task due to the use of natural raw materials. Apparently, several formulations were prepared and tested in laboratories. Each one of the formulations was tested and proved different compression strengths and transverse pressures not compatible with Jordanian standards. Hence, the optimization of block formulation should take into account Jordanian standards. The proportion of the raw material and the marble sludge in the batch is another important factor.

This study aimed to maximize the substitution of marble sludge for the natural fine limestone as raw material. However, the best results were achieved when marble sludge and medium and coarse sized gravel of limestone were present, whereas complete substitution of fine sand or fine limestone resulted in materials with poorer properties. As far as the manufacture and commercialization of building blocks are concerned with the incorporation of marble sludge, this study has shown that optimal proportion of the raw material in medium and coarse limestone fractions in the batch formulation potentially results in superior building blocks.

In particular, the powder of marble sludge featured with great modifications in the industrial production line is added. On the other hand, the presence of marble sludge considerably lowered the water absorption (<7%) and firmly increased the compression strength (>7.5 N/mm^2), compared to the commercial or traditional blocks (3 N/mm^2). 178 formulations were prepared to examine the proper formulation that fits the national and the international standards. Just five of them were promising, and two were chosen for commentary purposes (see Table 4). The different formulations were prepared by mixing the un-sieved and sieved marble sludge in the form of sludge directly taken after pressing sludge at the end of marble manufacture process, and other formulations after air drying as aggregates, and best after breaking aggregates and sieving them with and without cement in different proportions.

Sieved powder (Figure 3) with the as-received materials of gravels of limestone A (gravels of 6-9 mm in diameter) and gravels of limestone B (gravels of 3-5 mm in diameter) and black cement (Table 4) were mixed and blended to get building blocks. The marble sludge substitutes the fine limestone (sand powder) that was previously used in the ordinary mixture used to manufacture normal building blocks. According to the experimental results, all of the sludge in this study contained more than 50% of ash, and had no or very low, non-detected content of heavy metal. Therefore, the sludge did not belong to hazardous waste and can be classified as inert. Sludge incorporation had negligible effect on density, shrinkage and plasticity during all stages of the production process, anticipating some modifications in the industrial production line.

Lab measurements were undertaken and loading pressure was examined to see the adequacy of such produced blocks to the chosen standards (Table 5). The results are illustrated in Table 5, which shows the adequacy of the results obtained. The experimental results and their theoretical interpretation show that suitable incorporation of marble sludge can result in construction blocks of 10, 12, 15 and 20 cm with superior properties, while plant scale indicates that blocks can be manufactured from marble sludge so that, for blocks of 15-cm category, there were two formulations. The first formulation was number four in terms of water absorption (7%) and loading strength was (7.8 N/mm^2 against 3 N/mm^2 in Jordanian standards) (Table 5 and Figure 1). The second formulation was number seven for blocks of 10 cm, water absorption was (7%) and loading strength was (7.01 N/mm^2) (Tables 5 and 6 and Figures 3 and 4).

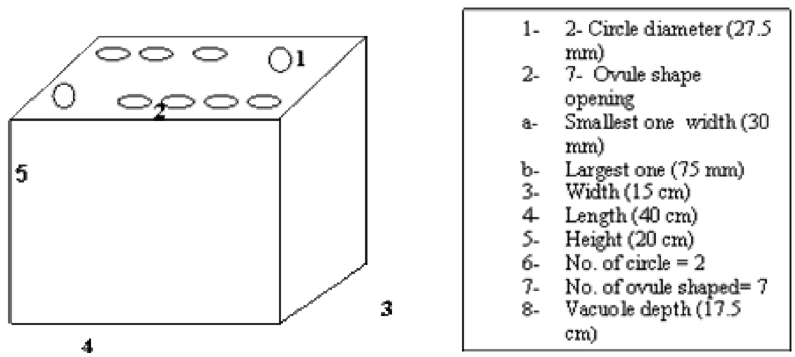

Figure (2): **Produced 15 cm - building block features as referred to templates or mould matrix (weight 14.5 kg).**

Figure (3): Marble sludge powder sieving.

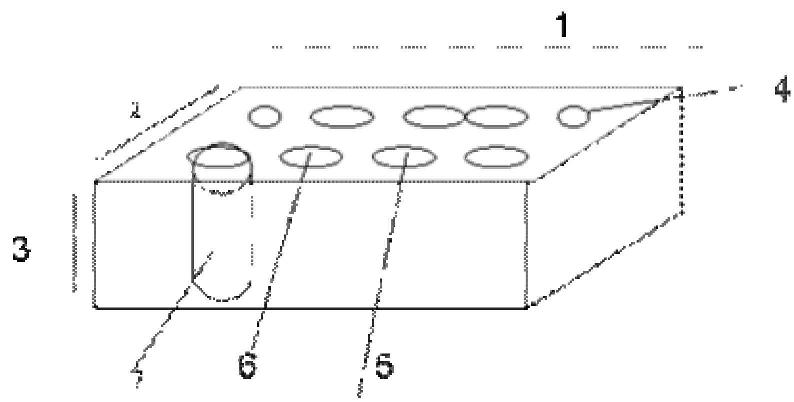

Figure (4): Produced 15 cm - building block features as referred to templates or mould matrix (weight 12.414 kg).

Table (4): The proportion of the blended materials (block mixture) on volume base.

Formulation	**Gravel A (volume base)**	**Gravel B (volume base)**	**Sand powder (volume base)**	**Black cement**	**Marble sludge (volume base)**
1	0.5	0.5	0.0	1 kg	1
2	1	1	0.0	1 kg	1
3	2	2	0.0	1	3
4	2	0.5	0.0	1	1
5	2.5	2.5	0.0	1	4
6	4	0.0	0.0	1	1.5
7	1	2	0.0	0.75	1.5
8 blank	1	1	1	1	0.0

Table (5): Loading strength as tested in laboratory (N/mm^2).

Formulation	**Loading Strength (N/mm^2) or MPa**	**Comments**
1	2.7	Similar to the commercial formulation
2	0.9	Very fragile
3	0.6	Very fragile
4	7.8	The passing formulation
5	2.6	Needs modification in formulation
6	3.5	Needs modification in formulation
7	7.01	The selected formulation for the decrease in cement quantity
8 blank	2.9	The commercial blend as randomly selected from factory

Table (6): Detail measurements obtained from sample number seven.

Sample No.	**Sample Dimensions**							**No. of holes (A_{h1})**	**No. of holes (A_{h2})**
	1	*2*	*3*	*4*	*5*	*6*	*7*		
7	40	10	20	2.5	7.5	2.5	17.5	2	7
*	**Wt. (kg)**	**Block 10 cm** A_{h1}	A_{h2}	**Total Area (cm^2)**	**Voids area (cm^2)**	**Eff. Area (cm^2)**	**Load (kN)**	**Strength (kg/cm^2)**	**Strength (N/mm^2) or MPa**
7	12.414	9.8	103	400	112.8	287.2	201.2	71.5	7.01
* 7	**V, (Total) (cm^3)**	**V, (Voids) (cm^3)**	**Eff. Volume (cm^3)**	**Density (g/cm^3)**					
	8000	1974.77	6025.23	2.06					

The values in Table (1) make further sense if compared with the other formulations that were omitted from the selected samples. The incorporation of marble sludge resulted in blocks with relatively high water absorption values and poorer flexural strength values than the produced blocks in the selected samples (i.e. 12–18% and 0.1–1.9 MPa).

The higher amount of water absorption measured in this work with the omitted samples is due to the different experimental procedure (i.e. mixing, drying and / or wet states). Sludge incorporation had negligible effect on density, shrinkage and plasticity during all stages of production, anticipating some modifications in the industrial production line. The superior behavior of the investigated formulations is also shown by the small differences in water absorption for several selected formulations. The selected results are formulae number seven and four, the detailed measurements are listed and indicated in Table (3) with respect to Figure (2) for sample number seven.

At this point, it must be underlined that the chosen samples were adopted to be the representative samples and the adequate formulations for commercial blocks exhibit water absorption definitely lower than 7% because they obviously satisfy the ISO regulations for traditional ceramics, such as bricks, or roof and floor tiles. Thereby, there is a high tolerance for incorporating large amounts of suitable wastes as raw materials (Ferreira et al., 2003) and (Ferreira et al., 1999).

The experimental conditions followed in this work and the results obtained purposefully increased the gap between the properties of the tested and chosen formulations and the commercial one and thus facilitated their comparison, especially when using waste materials as raw materials. The best target market for absorbing and consuming such products is the construction sector primarily in Jordan as such forms of blocks are not common in other countries. It is of benefit to spread such product all over the world which is made of recycling solid wastes produced in enormous amounts, such as marble or other cutting rock wastes (Menezes et al., 2002) and (Ferreira et al., 2002).

CONCLUSIONS

(a) The incorporation of marble sludge wastes in building blocks' production has proven to be safe for health and environmentally friendly.

(b) There are optimal proportions of the raw materials in the batch that satisfy the closest Jordanian standards as well as the global seeking to find alternatives and recycling of wastes. The so-manufactured blocks exhibit superior properties compared to commercial building blocks, with regards to water absorption and compression strength.

(c) The incorporation of marble sludge reduces natural resource consumption and reduces landfill occupation areas.

(d) The incorporation of marble sludge reduces deposition on agricultural lands and so saves ecosystems and environment.

REFERENCES

Colangelo, Francesco et al. 2004. Propeerties of Self-Leveling Concrete Made with Industrial Wastes. *International RILEM Conference on the Use of Recycled Materials in Buildings and Structures*, 8-11 November, 2004. Barcelona-Spain.

Fernandes, H.R., Torres, P. S., Agathopoulos, Tulyaganov, D. and Ferreira, J.M.F. 2003. Utilization of Solid Wastes from Granite Cutting Processing in Porcelain Industry. *Al-Azhar Bulletin of Science*, March, 33-43.

Ferreira, J. M. F., Torres, P. M. C., Silva, M. S. and Labrincha J. A. 2002. Recycling of Sludges Generated from Natural Stones Cutting Processes in Ceramic Formulations. In *Proceedings of the Recycling and Waste Treatment in Mineral and Metal Processing: Technical and Economic Aspects*, ed. B. Björkman, C. Samuelsson, and J.O. Wikström. Luleå University of Technology, Luleå-Sweden, 389-396.

Ferreira, J.M.F., Alves, H.M. and Mendonça, A.M. 1999. Inertization of Galvanic Sludges by Incorporation in Ceramic Products. *Boletin de la Sociedad Espanola de Cerámica y Vidrio,* 38:127-131.

Ferreira, J.M.F., Torres, P.M.C., Silva, M.S. and Labrincha, J.A. 2003. Recycling of Granite Sludges in Brick-type and Floor Tile-type Ceramic Formulations. *Euroceram. News*, 14:1-5.

Karasahin, M. and Terzi, S. 2004. Use of Marble Waste Dust in the Mixture of Asphaltic Concrete As Mineral Filler. *Euro Bitume*, Viyana.

Mehta, P. K. 2002. Greening of the Concrete Industry for Sustainable Development, *Concr. Int.,* 24: (7): 23-27.

Mehta, P. K. 2001. Reducing the Environmental Impact of Concrete, *Concr. Int.,* 23 (10): 61-65.

Menezes, R.R., Ferreira, H.S., Neves, G.A. and Ferreira, H.C. 2002. The Use of Granite Wastes as Ceramic Raw Materials. *Cerâmica* 48: 92-101.

Perez- Sirvent, C. et al. 2007. Metal-contaminated Soil Remediation by Using Sludge of the Marble Industry: Toxicolgical Evaluation. *Environment International*. 33 (4): 502-504.

Puzinauskas, V.P. 1983. Filler in Asphalt Mixtures, The Asphalt Institute, Research Report No. 69/2, Maryland, USA.

Terzi, S. 2000. An Investigation of Use of Marble Dust in Asphalt Concrete as Mineral Filler, MSc Thesis, S.Demirel University, Institute of Science. Isparta, Turkey.