

SELF-COMPACTING CONCRETE USING MARBLE AND GRANITE SAWING WASTES AS FILLER

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Abstract

Self-Compacting Concrete (SCC) is a mixture designed to flow and fill formworks without vibration. This performance is obtained by adjusting mixture components to produce both a fluid and stable mixture. SCC has been described as "the most revolutionary development in concrete construction for several decades". Originally developed to offset a growing shortage of skilled labor, it has proved to be economically beneficial because of a number of factors, including: faster construction, reduction in site manpower, better surface finishing, easier placing, improved durability, greater freedom in design, thinner concrete sections, reduced noise levels, absence of vibration, safer working environment. SCC has now been taken up with enthusiasm across Europe, for both site and precast concrete work. This concrete is able to flow under its own weight and completely fill the formwork, even in the presence of dense reinforcement, without the need of any vibration, whilst maintaining homogeneity. Nonpozzolanic fillers are frequently used to optimize the particle packing and flow behavior of cementitious paste in SCC mixes. Limestone filler has been the traditional material used in controlling segregation potential and deformability of fresh SCC.

During the sawing of the ornamental stones in Espírito Santo state (Southeast of Brazil) a great amount of waste material is produced (65 thousand tons of waste per month), a by-product in the production of marble and granite slabs during the sawing process of rocks with an equipment called gang-saw, which in most cases are deposited at companies yards or deposited into water bodies. These wastes cause environmental degradation with pollution and contamination of water and soil. The technical feasibility of the utilization of marble and granite sawing waste (MGSW) as a filler to SCC was studied. This paper deals with the influence of finely ground MGSW on properties of SCC mixes in the fresh and hardened states. The aim of this work is to provide an overview of the possibility to use MGSW as alternative to concrete raw materials focusing the use in SCC as an economical and environmentally safe alternative for recycling wastes.

1. Introduction

Some scientists believe that the unsustainable development age started around 100 years ago. During this period, the world population grew amazingly, generating fast urbanization followed by technological choices that resulted in an enormous waste of natural resources and energy. This industrialization was responsible for an increasing demand of concrete and cement, making the cement consumption grow from 2 million tons in 1880 to 1.3 billion in 1996 (Metha 1999).

Also according to Metha (1999), the Portland cement concrete appears as the ideal material for the infrastructure demands of the 20th century. It is not surprising that the concrete industry is the biggest consumer of natural resources as water, sand and rocks. This is the critical aspect about the sustainable development of the concrete industry.

The ornamental stone industry, closely related to the building industry, is also responsible for several environmental impacts since the exploration until the slab polishing and the tile cutting stages. These impacts include dust, noise and vibration, mud and stone fragments. About 30% of each granite or marble block is wasted during the sawing process, generating residue in the form of mud and causing severe environmental impact.

Only in the state of Espírito Santo, Brazil, about 65,000 tons of marble and granite sawing waste (MGSW) are generated each month.

Nevertheless, low cost ecological technologies are available nowadays, as the use of substantial amounts of industrial by-products into conventional concrete mixtures. In the state of Espírito Santo, for instance, all the three cement plants produce the CP-III RS cement with up to 70% of portland blast-furnace cement contents (ABNT 1991). Moreover, two of these cement plants produce only this kind of cement.

The development of special kinds of concrete, as the self-compacting concrete (SCC), is a positive contribution to the sustainable development of the concrete industry due to the need of using great amounts of industrial by-products in the form of filler (Gomes 2003). Its employment appeared as a solution to the production of concretes whose durability are independent upon skilled workers, since it does not require vibration (Okamura 2003).

This article presents first hand, the high strength self-compacting concrete with marble and granite sawing waste (MGSW), a very abundant residue in many ornamental stone producing and processing countries. The physical and chemical characteristics of this residue make it the ideal replacement for limestone filler, traditionally used in this kind of concrete.

2. Industrial Ecology

No industry exists independently; each one is linked to another through transactions and activities. Industrial Ecology (IE) is a new approach to the industrial design of products and processes and the implementation of sustainable manufacturing strategies. (Jelinski et al. 1991)

“Industrial Ecology is the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural, and technological evolution. The concept requires that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them. It is a systems view in which one seeks to optimize the total material cycle from virgin material, to finished material, to component, to product, to obsolete product, and to ultimate disposal. Factors to be optimized include resources, energy, and capital.” (Graedel & Allenby 1995)

An increasing aspect in industrialized products is the “dematerialization”, i.e., the use of less material to obtain the same function (Graedel & Allenby 1995). Some examples of this tendency in the concrete industry are the High Strength Concrete (HSC) that presents a compressive strength 2 or 5 times higher than the traditional concrete typical values, and the Reactive Powder Concrete (RPC), with fck varying from 200 until 800 MPa. These two concretes present, in the same loading conditions, a reduction in the sections of structural elements, with a consequent reduction in the use of raw materials and energy. Comparing an RPC beam weighing 130 kg/m to a prestressed concrete beam weighing 470 kg/m, it is possible to obtain a reduction of 72% of material for equal moment capacity beams. Thus, it is clear that the RPC beam requires much less material than the prestressed concrete beam.

A second trend to complement the use of smaller amounts of material is the substitution of certain products for other ones which cause less environmental impact, or even the substitution of certain technologies for cleaner ones.

Due to the need of using great amounts of fillers to meet the self-compaction requirements, the self-compacting concrete uses several kinds of waste materials in its composition, both as filler and as substitutes for cement. It includes: ground granulated blast furnace slag, fly ash and lignite fly ash, silica fume, ground ceramic waste, quarry dust and, as presented in this article, marble and granite sawing wastes.

Another strong trend is the change in the energy and time utilization standards, called *decarbonization*. Countries as The USA, South Korea, Japan and the UK show a decrease in *industrial energy intensity*, which is a parameter to measure the relative efficiency in the use of energy, expressed in currencies. This can be seen in the reduction of burned carbon intensity to produce energy that has taken place in several

developing countries. Since the use of fossil fuels is closely related to pollution, this trend contributes to decrease CO₂ emissions.

In the last years, concrete technology has proposed a few solutions to get adapted to this new industrial policy. Since for each ton of Portland cement clinker produced a ton of carbon dioxide is released in the atmosphere, new measures as the use of fly-ash in great amounts have been proposed to contribute to decrease CO₂ emissions (Metha 2002).

3. Dimension Stones Industry

Table 1 represents the data of the world's dimension stone production in 2001 (DNPM 2003). According to these statistics, Brazil ranks sixth among the world's dimension stone producers.

Table 1 Dimension Stones World Production in 2001

Country	China	Italy	India	Spain	Iran	Brazil	Portugal	Turkey	USA	Greece	Other	Total
Production (10 ³)	11,400	8,385	5,980	5,525	4,000	3,059	2,405	2,275	1,820	1,625	16,664	63,138
%	18.1	13.3	9.5	8.8	6.3	4.8	3.8	3.6	2.9	2.6	26.4	100.0

The state of Espírito Santo, located in the southeast of Brazil (figure 1) has one of largest deposits of marble and granite in the country (Sindirochas 2004).



Figure 1 The Espírito Santo state localization in Brazil

3.1 Marble and Granite Production Process

During the mineral research, the production process involves basically the exploration of the deposits, the processing (sawing and polishing) and the supporting areas. In all the stages, there are environmental impacts (water, air and soil). In the extraction stage, there is a loss of about 40% of the rock, due to inappropriate cuts and material flaws or cracks.

After being extracted, the blocks are transported to the stone industries for sawing, when the blocks are cutted into slabs between 1 - 3 cm thick. This process uses machines called gang-saws. In the state of Espírito Santo there are about 900 gang-saws, which represents 57.2% of all gang-saws in Brazil. During the sawing process, around 30% of the block turns into mud (figure 2), named in this article marble and granite sawing waste (MGSW).

This mud is deposited in decantation ponds (figure 3) or dumped into water bodies causing enormous environmental impact.

The production of waste in the form of mud is of around 800,000 tons per year, only in the state of Espírito Santo. After the sawing process, the slabs are polished and cut into tiles, and then taken to the market.

In this study, just the use of the waste resulting from the blocks sawing will be approached.



Figure 2 Marble and granite sawing waste (mud)



Figure 3 Marble and granite sawing waste deposited in decantation ponds

3.2 Characterization of the Residues

A wide morphological, physical, chemical and environmental characterization was conducted by Silva (1998), proving the feasibility of the use of the waste as building material.

The specific gravity of the MGSW is 2.78g/cm³. The average diameter of the grains is 6.74 μm and Blaine fineness of 1,295 m²/kg.

The chemical composition of the residue shows few variations, as shown in table 2.

Table 2 Chemical composition of MGSW (wt.%)

Author	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	N ₂ O	K ₂ O	TiO ₂	SO ₃	Na ₂ O	Loss on ignition
Gonçalves (2000)	59.62	9.49	12.77	4.83	1.96	-	5.3	-	0.03	2.72	1.92
Neves <i>et al.</i> (1999)	68.88	3.59	15.98	1.54	-	2.42	4.82	-	-	-	-
Silva <i>et al.</i> (1998)	59.95	6.05	10.28	6.51	3.25	-	4.48	0.92	-	3.39	-

3.3 Building Applications of MGSW

There are both regional and national significant efforts in order to find applications for the abrasive mud. In general, through researches about the potential use of the MGSW in the building industry, road paving and in the ceramic and cement industries. In Brazil, there are prominent researches by Calmon *et al.* (1997) and Calmon *et al.* (1998) which investigated the use of MGSW in mortars and soil-cement bricks; by Silva (1998), the first exhaustive characterization of the residue that lead to future researches; and by Gonçalves (2000) which proposed the use of the MGSW in conventional concrete. In the ceramic industry, works by Menezes *et al.* (2004) and Monteiro *et al.* (2004) are considered prominent.

The use of this residue is still incipient in Espírito Santo and in Brazil. Presently, just one ceramic brickwork industry in Espírito Santo uses about 500 tons/month of MGSW as partial substitution for clay.

4. The High Strength Self-Compacting Concrete (HSSCC) with MGSW

4.1 Introduction

In order to consider any concrete as self-compacting concrete, three requirements must be met (Bartos 2000):

- filling ability: ability to fill all the space under its own weight.
- passing ability: ability to flow through bars and openings under its own weight.
- segregation resistance: ability to keep its composition uniform during transport and cast.

The high strength self-compacting concrete is a special type of High Performance concrete (HPC) having the characteristics described in table 3:

Table 3 HSSCC Properties

Fresh concrete	Self compactability
Early age	Avoidance of initial effects
Hardened concrete	High compressive strength (> 40 MPa) High durability

These characteristics are obtained through the use of superplasticizers, optimizations of fine particles and volume limitation of coarse aggregate. Several different methods have been proposed for the SCC mix design (Gettu & Agulló 2003). The method used for this design was offered by Gomes (2002). According to this method, the design is divided in two distinct phases: paste optimization phase and aggregate skeleton optimization. In the first phase, an ideal paste for a pre-established w/c ratio is sought. In the second, the concrete aggregate skeleton is optimized – a reduction of void is sought. The concrete with the least paste volume to meet the self-compaction and compressive strength requirements is chosen as the ideal one.

4.2 Materials

The cement used is designated CP 40 III RS, produced by Itabira Agro Industrial S.A. (Nassau) with 60 to 70 % of granulated blast furnace slag content. It is similar to Type IS cement (American Classification), according to the ASTM C 595-93 standard. This portland cement is in common use in countries where slag is widely available, like Brazil. The ornamental stone sawing waste referred to above, is used after dried in stove and processed in a jaw crusher. The small aggregate used was white quartz sand with relative density of 2.65 g/cm³. A combination of 0 -19 mm (50%) and 0 - 9.5 (50%) coarse aggregate was used. Polycarboxylate Ether (PCE) superplasticizer, with 28.5 % a 31.5 % of solid content was used.

4.3 Proportions of HSSCC Mix

Table 4 shows the concrete mix proportion used in this article. In order to produce a concrete causing low environmental impact, it was tried to use of high slag content cement and to maximize the use of waste. About 20% of this concrete's mass (17% of its volume) are made of waste in the form of ground granulated blast furnace slag, as a cement constituent, and MGSW, as a filler.

Table 4 Composition of the HSSCC with MGSW

Material	Mass (kg/m ³)
Cement (CP III 40-RS)	430
MGSW	190
Fine aggregate 0 - 4 mm	826
Coarse aggregate 0 - 9.5 mm	395
Coarse aggregate 0 - 19 mm	395
Superplasticizer	6.75
Water	150

4.4 Fresh Properties

The slump flow test is the simplest and most widely used test method for self-compacting concrete (EFNARC 2002). Flowability was checked through slump flow test, using an Abrams cone, on a metallic plate. As seen in figure 4 the inverted cone procedure was adopted due to its easy usage (Ramsburg 2003). The total spreading noted was of 710 mm, calculated by the average of the two measured diameters (Figure 5). A value between 650 – 800 mm is required for SCC.



Figure 4 Inverted slump flow test

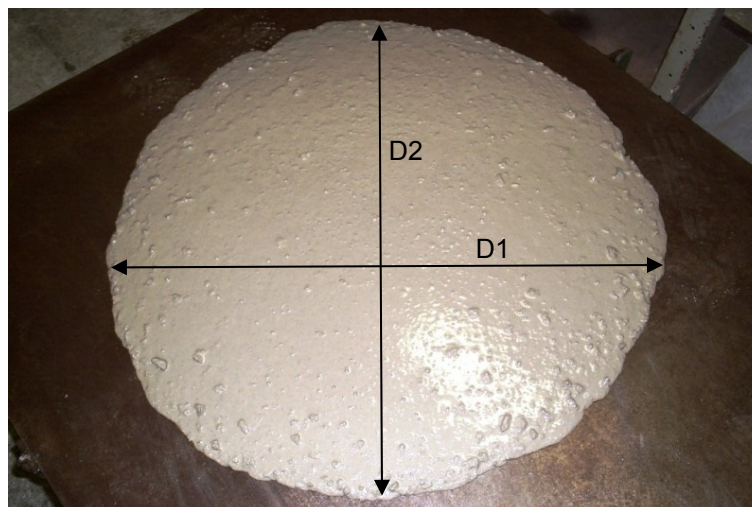


Figure 5 Final spread of HSSCC with MGSW

4.5 Hardened Properties

The figure 6 shows the concrete development of compressive strength with time. The compressive strength after 28 days was 69.3 MPa (standard deviation: 3.2 MPa).

This research proceeds and other properties are being investigated in order to confirm the technical, economical, and environmental feasibility in the use of MGSW in HSSCC.

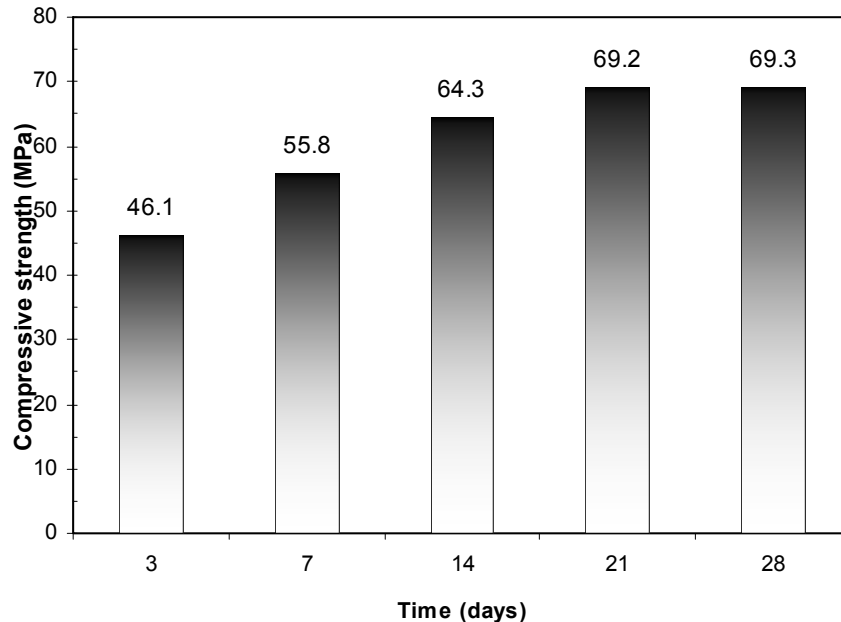


Figure 6 Development of compressive strength with time

5. Conclusions

Due to its high fineness and physical and chemical properties, the marble and granite sawing waste (MGSW) is an excellent filler to self-compacting concrete. Its employment avoids the use of limestone filler, commonly used in this type of concrete. This reduces the use of raw materials and energy in the self-compacting concrete production.

The high strength self-compacting concrete with MGSW, a special type of SCC presented in this article seems to be environmental-friendly. It occurs as a result of high employment of waste, raw materials economy and high durability.

Its use offers more interaction between the dimensional stone industry and the building industry. This increases the possibility of employing this residue in the civil construction, avoiding the water, soil and atmospheric pollution it causes.

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