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Fresh and hardened characteristics of self compacting concretes made with combined use of marble powder, limestone filler, and fly ash

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HIGHLIGHTS

- ▶ Use of fly ash (FA), marble powder (M), and limestone filler (LF) in self compacting concrete (SCC).
- ▶ Effect of multisystem blends of FA, M, and LF on fresh and hardened properties of SCC.
- ▶ Improved viscosity and flowability by inclusion of FA.
- ▶ Enhancement in durability related permeability properties by incorporation of fillers.

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ABSTRACT

One of the major environmental concerns is disposal or recycling of the waste materials. Marble processing plants and limestone quarries produce millions of tons waste dust in the powder form every year. Having considerable high degree of fineness in comparison to cement, these materials may be utilized as filler for production of self compacting concretes (SCCs). For this purpose, an experimental program has been conducted to investigate the possibility of using marble powder (M) and limestone filler (LF) in the production of SCCs with and without fly ash. Two series of concrete mixtures containing binary and ternary blends of fine materials were designed and cast with a constant water–binder ratio of 0.35. Test results showed that high replacement level of the filler slightly affected the fresh properties of the SCCs adversely. However, the inclusion of fly ash mitigated such problems. Moreover, mechanical and transport properties were improved by using marble powder and limestone filler.

1. Introduction

One of the major handicaps faced in reinforced concrete construction practices is compaction and placement of the fresh concrete through confined spaces such as areas of congested reinforcement. Self compacting concrete (SCC) is a concrete that can settle into the heavily reinforced, narrow and deep sections by its own weight to completely fill the formwork without any internal or external mechanical vibration [1]. The most important concern in SCC related studies is to provide stability and segregation resistance of fresh mix without loss of uniformity. Since its introduction to the construction industry in the early 1990s, there has been extensive research concerned with the appraisal of fresh and hardened properties of SCCs [2–6]. In order to provide high fluidity to SCC and to overcome the segregation and bleeding problems during transportation and placing, use of high amount of fine materials (Portland cement, fillers and fine sands, etc.) and utilization of viscosity modifying admixtures have been specified by investigators [7–11]. It has been shown that having powder content (materials finer than 0.1 mm) of 500–600 kg/m^3 is critical to achieve self-compatibility in the concrete [8]. As well as being uneconomical, the excessive use of cement is undesirable when the environmental aspects are taken into consideration. This situation leads the formulators to benefit from replacement powders, such as fly ash, silica fume, and ground granulated blast furnace slag. Utilization of such materials, not only reduces the cost, but also provides additional performance to SCCs [5,9].

Marble has been used as an important building material, especially for decorative purposes for centuries. During sawing, shaping, and polishing process, about 25% of the processed marble turns into dust or powder form. Turkey has 40% of the total marble deposits in the world such that 7,000,000 tons of marble have been produced in Turkey annually and 75% of it has been processed in nearly 5000 processing plants. It is obvious that the waste material of these plants reaches millions of tons, thus making the stocking

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Table 1
Chemical composition and physical properties of cement and mineral admixtures.

Chemical analysis (%)	Portland cement	Fly ash	Marble powder	Limestone filler
CaO	63.60	4.24	52.45	55.07
SiO_2	19.49	56.20	1.29	0.22
Al_2O_3	4.54	20.17	0.39	0.18
Fe_2O_3	3.38	6.69	0.78	0.44
MgO	2.63	1.92	0.54	0.34
SO_3	2.84	0.49	–	–
K_2O	0.58	1.89	0.11	0.11
Na_2O	0.13	0.58	–	–
Loss of ignition	2.99	1.78	43.90	42.86
Specific gravity	3.13	2.25	2.71	2.68
Blaine fineness (cm^2/g)	3387	2870	5190	3990

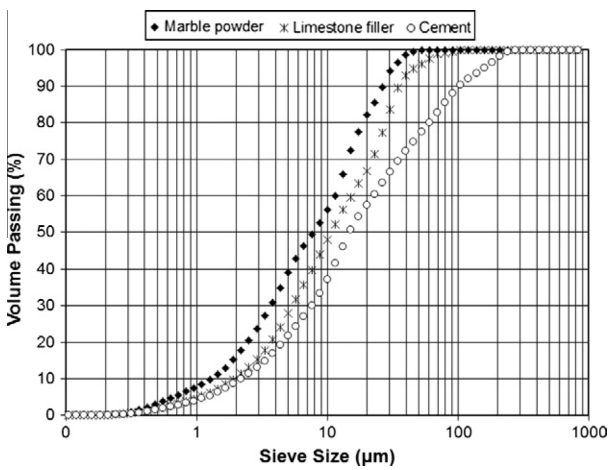

Fig. 1. Particle size distribution of marble powder, limestone filler, and cement.

of this amount of waste impossible [12]. Disposal of this waste material is one of the environmental problems worldwide today. However, they can be successfully and economically utilized to improve some fresh and hardened properties of self-compacting concretes (SCCs).

In the literature, use of marble powder in the concrete has not found adequate attention. Corinaldesi et al. [13] stated that since its high degree of fineness, marble powder was proved to be very effective in providing very good cohesiveness of mortar and concrete. Aruntas et al. [14] studied the self-compacting concrete containing binary blends of Portland cement and marble powder. They observed that use of marble powder aggravated the fresh properties of concretes by decreasing the slump flow diameter, associated with increasing the slump flow and V-funnel flow times. However, combined use of the marble powder in the binary and ternary cementitious blends requires more detailed investigations to clarify its effectiveness on the fresh and hardened properties of self-compacting concretes.

Having a property of physical improvement of the cement paste matrix, limestone filler (LF) is one of the materials that have extensively been studied in the literature [15–22]. Limestone filler improves the mechanical and durability features of concretes by providing more compact structure through its pore-filling effect. In the existence of fly ash, it also reacts with cement by binding $Ca(OH)_2$ with free silica by a pozzolanic reaction forming a nonsoluble CSH structure [16]. Ghrici et al. [20] produced, mortar prisms in which Portland cement was replaced by up to 20% limestone filler and 30% natural pozzolana. They tested the samples in flexure and compression at 2, 7, 28 and 90 days. Some samples were also tested for chemical attack and chloride ion permeability. It was shown that use of ternary blends of cementitious materials improved the early age and the long-term mechanical properties.

Table 2
Sieve analysis and physical properties of the fine and coarse aggregates.

Sieve size (mm)	Fine aggregate		Coarse aggregate
	River sand	Crushed sand	
16	100	100	100
8	100	100	31.5
4	86.6	95.4	1.0
2	56.7	63.3	0.5
1	37.7	39.1	0.5
0.5	25.7	28.4	0.5
0.25	6.7	16.4	0.4
Fineness modulus	2.87	2.57	5.66
Specific gravity	2.66	2.45	2.72

Durability was also enhanced against sulfate, acid, and chloride ion attacks. Menendez et al. [17] investigated the use of Portland cement with incorporation of limestone filler and blast furnace slag. They pointed out that the ternary composition of the binders provided economic and environmental advantages by reducing Portland cement production, thus CO_2 emission. Moreover, using binders in the ternary blends seemed to improve the early and later age compressive strengths.

2. Research significance

Using filling materials and mineral admixtures as substituting additives in concrete has a great tendency to fulfill the expectations in providing greater sustainability in the construction industry. The issues regarding the cost, recycling the industrial wastes, rehabilitation in durability and mechanical performance of concrete will therefore put a pressure on the utilization of such materials. The current study aims at highlighting the fresh and hardened characteristics of SCCs produced with binary and ternary systems of Portland cement, marble powder (M), limestone filler (LF), and fly ash (FA). For this purpose, two series of concrete mixtures were designed with respect to the inclusion of FA, whereas M and LF have partially replaced the total binder at the levels of 5%, 10% and 20%, by weight. Fresh properties of SCCs were tested for flow and passing ability, viscosity, initial and final setting times, while compressive and splitting tensile strengths were measured for determination of the mechanical properties. Moreover, chloride ion penetration, water sorptivity, and electrical resistivity (ER) were measured to evaluate the transport properties of SCCs produced in the study.

3. Experimental study

3.1. Materials

The SCC mixtures were prepared with CEM-I 42.5 R Portland cement (PC) conforming to the requirements specified in TS EN 197-1 [23], class F fly ash (FA) according to ASTM C 618, marble powder (M) obtained as a by-product of marble sawing and shaping, and limestone filler (LF) from a limestone quarry. The chemical