Construction and Building Materials 133 (2017) 425–432

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

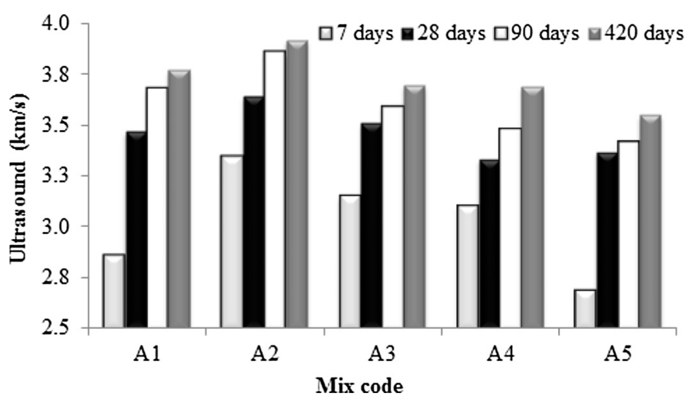
Concretes with synthetic aggregates for sustainability

Ilker Tekin [a], Muhammed Yasin Durgun [b], Osman Gencel [b], Turhan Bilir [c], Witold Brostow [d,*], Haley E. Hagg Lobland [d]

[a] Bayburt University, Faculty of Engineering, Department of Civil Engineering, Bayburt, Turkey
[b] Bartin University, Faculty of Engineering, Department of Civil Engineering, 74100 Bartin, Turkey
[c] Bülent Ecevit University, Faculty of Engineering, Department of Civil Engineering, 67100 Zonguldak, Turkey
[d] Laboratory of Advanced Polymers and Optimized Materials (LAPOM), Department of Materials Science and Engineering and Department of Physics, University of North Texas, 3940 North Elm Street, Denton, TX 76207, USA

GRAPHICAL ABSTRACT

Variations in ultrasound pulse velocity for different concretes according to age. The trend in compressive strength behavior of the concretes is similar.



ARTICLE INFO

Article history:
Received 16 July 2016
Received in revised form 30 October 2016
Accepted 21 December 2016

Keywords:
Sustainable concrete
Waste marble
Fly ash
Marble dust
Industrial concrete aggregates

ABSTRACT

We have used waste marble aggregates, marble dust and fly ash from thermic power plants as fillers in concretes for replacing natural aggregates. We have used two different kinds of cements. After curing, we have determined the workability (by slump tests), air content, unit weight, Schmidt hardness, ultrasound pulse velocity, compressive strength and carbonation depth. The concretes containing waste marble at least match or exceed the workability and strength of the control concrete type. Fly ash significantly improves the workability. Utilizing waste marble aggregate at the replacement ratio of 100% along with waste marble dust, fly ash and pozzolanic cements in concrete leads to lower cost – achieving at the same time environmentally friendly production process with decreased consumption of natural resources and energy. Our work also contributes to enhancement of sustainability by finding a use for marble waste and fly ash.

* Corresponding author.
E-mail address: wbrostow@yahoo.com (W. Brostow).

http://dx.doi.org/10.1016/j.conbuildmat.2016.12.110
0950-0618/

1. Introduction

More and more materials to be used for any application are considered not only from the point of view of properties and cost, but also from the point of view of sustainability [1–3]. Therefore, materials based on waste have an advantage over virgin ones. In the case of concretes, other factors that need to be considered are light weight [4,5] and the service environment [6].

Turkey has significant marble reserves that constitute over 40% of total worldwide reserves. Over 7 million tons of marble are produced in Turkey annually. Egypt produces over 50 different types of marble and granite—with annual production of approximately 3.5 million tons [7]. While marble blocks are being processed, *marble wastes* are produced as dust and aggregates. Stored marble waste constitutes an environmental hazard [8]. Already in 2009, 1400 tons of waste marble per day were stored in depots in Turkey [9]. Similarly, waste from the cutting and sawing process in Brazilian decorative stone industry constitutes 20–25% of the total volume of the blocks [10]. Likewise, Hebhoub et al. [11] have reported on the considerable waste generated during marble production; almost 70% of the mineral gets wasted in the mining, processing and polishing stages—with an obvious impact on the environment.

The environmental impact of marble waste could be lowered in a cost-effective manner by utilizing the waste material in value-added applications. Some of us have demonstrated [12] the feasibility of using marble waste as aggregate in concrete paving blocks. Further, it has been shown in the same work that blocks prepared from a cement called CEM with marble waste substituted for a portion of the aggregate exhibits suitable mechanical strength along with improved freeze-thaw durability and abrasive wear resistance in comparison to controls.

Depending on the application, a choice has to be made between mineral and polymer concretes [13]. Previously we have considered the use of marble powder and other fillers in polymer concretes [14]. We now discuss effects of fillers in mineral concretes that are byproducts of industrial processes, therefore quite cheap, and finding use for these byproducts contributes to protection of our environment.

Fly ash (FA) is a by-product of coal thermal power plants. There are estimates showing that fly ash is created worldwide in the amount of some 500 million tons every year [15,16]. There is no dispute that fly ash by itself causes environmental pollution. Storage costs of fly ash are quite high—and constitute a palliative only. Given those costs, at some point the storage would have to stop—even if it suddenly became more affordable. Clearly progressive accumulation and storage of fly ash goes against the very idea of sustainability.

There are possibilities of using fly ash in mortar and concrete, an effort in which we also participate [16–20]. Thus, it is already known that fly ash improves mechanical properties as well as freeze–thaw resistance, sulphate resistance, alkali–silica reaction, durability and abrasion resistance when used as a supplementary cementitious material. Also, shrinkage and permeability of hardened concrete are decreased, a consequence of the filling of micropores. Still further, fly ash also reduces the chloride penetration and steel corrosion in concrete [17,18,20]. On the other hand, the usage of industrial waste materials in concrete mitigates the pollution and at the same time has a positive effect on the economy of a given country [17]. In Turkey, the annual fly ash production is about 18 million tons annually, more than all other industrial waste combined [21]. In India, approximately 80 million tons of fly ash are generated each year [22].

Until recently, marble wastes have been utilized as a *partial* replacement of natural aggregates. It is our intention to replace traditional fine and coarse aggregates fully by marble fine and coarse aggregates.

André and coworkers [23] used marble industry waste. Baeza-Brotons and coworkers [24] used sewage sludge ash in Portland cement systems. Bravo and coworkers [25] used aggregates from construction and demolition recycling plants. Discarded tire rubber has been used by Thomas and Gupta [26].

Our work reported below consisted of two series. In the first series we have mixed waste marble aggregates with CEM I 42.5 Portland cement. In the second series we have used CEM IV pozzolanic cement—in order to evaluate the effects of natural pozzolans. Moreover, fly ash has also been utilized to replace a portion of the cement.

2. Materials and methods

2.1. Cement

We have used Portland cement CEM I 42.5R, subsequently called A1, and CEMIV/B-M (P-LL) 32.5 R, subsequently called A5, (with trass) donated to us by Bati Soke Cement Factory. These materials comply with the requirements of the Turkish TS EN 197-1 [27] standard, equivalent to the European Standard EN 197-1. These cement types are commonly used in construction. Their properties are summarized in Tables 1 and 2.

2.2. Fly ash

Fly ash (FA) used is in compliance with ASTM C 618 [28]. The use of FA as an additive in cement based concretes is classified in ASTM C 618 into two types, as class C and class F. Content of major oxides, $SiO_2 + Al_2O_3 + Fe_2O_3$, must be more than 50% for class C and more than 70% for class F. Our FA belongs to the F type since its total of major oxides amounts to 79.4%. Our fly ash was obtained from the Yatagan thermal power plant, Mugla, Turkey. Its chemical composition is provided in Table 2. The respective Blaine fineness which serves as a measure of the particle size, or fineness of cement including supplementary cementitious materials, is

Table 1
Physical and mechanical properties of cements.

	A1	A5
Initial setting time (min)	146	169
Final setting time (min)	195	218
Le Chatelier (mm)	1	0.5
Specific gravity (g/cm^3)	3.13	2.92
Specific surface (cm^2/g)	3604	4623
Standard consistency (%) (water demand)	29.7	30.2
Compressive strength @ 2 days (MPa)	26.4	18.6
Compressive strength @ 28 days (MPa)	55.6	38.0

Table 2
Chemical analysis of cements and waste marbles (wt.%).

Compound	A1	A5	Fly ash	Waste marble
SiO_2	18.9	30.9	52.4	0.1
Al_2O_3	4.8	7.3	21.2	–
Fe_2O_3	3.6	3.5	5.8	0.1
CaO	64.7	47.3	9.4	52.2
MgO	0.9	1.2	2.1	1.8
SO_3	2.8	2.5	1.4	–
Na_2O	0.2	0.2	0.5	–
K_2O	0.8	1.1	1.2	–
Free CaO	1.5	1.7	–	–
LOI*	2.9	1.9	5.8	46.2

* Loss on ignition.