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Effect of the marble fineness on the rheological characteristics of concrete

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ABSTRACT/RESUME

Abstract: *The objective of this experimental work is to study the effect of the marble fineness on the rheological behavior of ordinary concrete at fresh and hardened states. Five (5) types of concrete were made: a control concrete with cement CEMI/42.5 and four other concretes where CEMI cement was partially replaced by marble powder at the rate of 5% and 10% with two Blaine finesses: 2400cm²/g and 7000cm²/g. The rheological parameters of the concrete were measured using the ICAR rheometer and the compressive and flexural strengths were determined on 10x10x10cm³ cubic specimens and on 7x7x28cm³ prisms, respectively at different times (3, 7, 28 and 60 days). The results obtained showed that the optimum in marble powder should be equal to 5% and without a high grinding (2400cm²/g); the concrete retains its rheological characteristics at fresh state and its mechanical properties at hardened state. For a replacement rate of 10% and a fineness of 7000cm²/g, the yield stress of the concrete increases considerably, although the mechanical strengths are important.*

I. Introduction

The rheological behavior of fresh cement paste and concrete is a subject of considerable interest. Fresh concrete is a fluid material and its rheological behavior affects or limits even the way it can be treated. Therefore, the measurement and control of rheological parameters are very important in the production of quality concrete. Several studies [1] have been conducted to improve the rheology and mechanical properties of concrete using a variety of fine particles and have reported that adjuvants may contribute to increased workability in the fresh state, densify the microstructure, and to develop higher mechanical properties due to their latent hydraulic properties and their pozzolanic reaction [2].

Zhang & Han [3] have studied the effect of ultrafine additions on the rheological properties of cement pastes and find that the yield stress increases with the amount of ultrafine addition incorporated while the viscosity of the paste varies with the nature and the amount of addition. When the degree of substitution of the cement by additions of silica fume, fly ash or limestone is less than 15%, the viscosity of the paste is remarkably reduced. This was not noted for slag additions. Adjoudj [4] showed that for mortars containing slag or limestone, handling is slightly improved at around 10% of the substitution rate.

The fillers are products obtained by fine grinding or spraying of certain natural rocks, acting on certain qualities of cement with their appropriate size. Limestone fillers are the most used in Algeria. These fillers have often been considered inert. But according to other authors, limestone is an important factor in the hydration of C_3A, as well as C_3S and β-C_2S, in the presence of $CaSO_4$ and lime. Limestone fills the pores between cement particles due to the formation of carbo-aluminate phases [5]. It is concluded that in pastes containing $CaCO_3$, either as a chemical reagent or as a limestone constituent, transformation of ettringite to mono-sulfate is delayed, while calcium aluminate mono-carbonate is preferably formed. Instead of mono-sulfate even at an early age. In addition, hydration of calcium silicates is accelerated [6 -8]. This explains the high resistance of cement at young age [9]. Ramezanianpour [10] have shown that limestone Portland cement (PLC) concrete with up to 10% limestone provides competitive properties with PC concretes.

The use of marble powder (almost 100% $CaCO_3$) as a replacement for cement has recently been the subject of several research projects. Agarwal & Gulati [11] have shown that the presence of marble powder in the cement matrix improves compressive strength at early age. Topçu [12] and Alyamac & Ince [13] have shown that the four different marble powders produced in Turkey characterized by Blaine fineness between 3900 and 5100 (cm^2/g) can be used successfully and economically as than filler in self-compacting concrete. Miss Meera et al., [14] have shown that the rheological properties presented similar and linear inter-relationship between self-compacting concrete (SCC) made of marble and granite powders and control concrete mix. Alyousef et al., [15] have shown that the use of marble powder as a filler SCC composition increases intruded pore volume, reduces of fine pores and then increases compressive strength. For other authors, the incorporation of 8% of marble powder resulted in a reduction of mortar strengths. On the other hand, Valeria [16] showed that the substitution of 10% of sand by marble powder in the presence of a super-plasticizing admixture provided a maximum compressive strength at the same level of maneuverability comparable to that of the reference mixture after 28 days of hardening. Kabeer & Vyas [17] showed that the mortar mixes with 20% substitution of river sand by marble powder can be used for masonry and rendering purposes. Also, Aydin & Arel [18] revealed that the replacement of up to 60% of the cement constituent by marble powder in paste mixtures was effective for various applications in the manufacturing bricks, tiles and controlled low strength applications. In addition, an even more positive effect of marble powder is evident at an early age, because of its filling capacity. Moreover, an even more positive effect of marble powder is evident at early ages, due to its filler ability. Marble dust not only improves the physical characteristics but also provides an environmentally friendly route for waste disposal and creation of more sustainable concrete [19].

To reduce energy consumption and CO_2 emissions and increase production, cement manufacturers use mineral additives such as slag, pozzolana and limestone.

The objective of our study is to experimentally assess the contribution of the grinding of marble powder from marble waste to the rheological behavior in the fresh state and the hardened state of ordinary concrete. The experimental work is started on concretes where portland cement is partially replaced by marble powder at the rate of 5% and 10% with two Blaine finesses: the marble powder collected from the marble works with a Blaine specific surface (SSB) of $2400cm^2/g$ and ground to a SSB of $7000cm^2/g$. The rheological parameters of the concrete were measured by the ICAR rheometer.

II. Materials and tests

II.1. Natural aggregates (gravel and sand)

In this experimental study, local materials were used.

Two gravel fractions (3/8 and 8/15) were used to make concrete. They come from the crushing of rocks in a quarry located in the Bordj Bou Arréridj Wilaya. Two types of sands (0/5) were used: crushed sand (CS) and dune sand (DS). The dune sand is characterized by a very low fineness modulus 0.91 and the crushed sand has a very large fineness modulus of about 3.2 and that is why we had to mix the two sands in order to have a sand of better quality and after several variants, we were opted for an optimum mix (S) namely 25% of DS and 75% of CS, whose fineness modulus was of the order of 2.2 and a sand equivalent of 85.3.

Table 1 presents the physical properties of the different aggregates (gravel and sand).

Table 1. *Physical Properties of Aggregates*

Elements	Absolute density (kg/l)	Apparent density (kg/l)	compactness (%)	Porosity (%)	Abrasion resistance (L.A)
G (3/8)	2.71	1.54	58	42	25.01
G (8/15)	2.57	1.56	59	41	23.80
S(0/5)	2.61	1.74	64	36	------

II.2. Cement

The cement used is a CEMI/42.5. Its physical characteristics and the chemical (X-ray fluorescence) and mineralogical (BOGUE formula) compositions are given in Tables 2 and 3, respectively.

Algerian Journal of Environmental Science and Technology
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Table 2. *Physical characteristics of cement*

Density	Fire loss (%)	Blaine fineness (cm^2/g)	Initial setting time (min)	Final setting time (min)	Normal consistency (W/C)	80µ refusal (%)
3.22	1.43	**2943**	185	285	0.25	3.4

Table 3. *Chemical and mineralogical compositions of cement (% by weight)*

SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	Na_2O	C_3S	C_2S	C_3A	C_4AF
21.63	4.42	4.99	62.57	0.33	0.15	55.78	25.20	3.28	15.17

II.3. Marble powder

The marble powder used was collected directly from cutting workshops marble plates. Its physicals characteristics and chemical composition are presented in Tables 4 and 5.

X-ray diffraction analysis (Figure 1) shows that it is composed solely of calcite (100% $CaCO_3$), which explains its color and appearance: white [20]. It had a Blaine fineness of 2400cm^2/g, then it was ground using a ball mill to reach a Blaine fineness of the order of 7000cm^2/g. The cement CEMI/42.5 whose Blaine fineness is 2943cm^2/g was partially substituted by the marble powder at a rate of 5% and 10% with the two finesses. Table 6 shows the chemical and mineralogical compositions of cement CEMI/42.5 and the two binders: CEMI/42.5 + 5% marble powder and CEMI/42.5 + 10%.

Note that the chemical composition of cement CEMI/42.5 has not changed substantially by replacing part (5% or 10%) with marble powder. All elements have undergone an insignificant decrease.

Table 4. *Physical characteristics of marble powder*

Density	Blaine fineness (cm^2/g)		Color	pH	Inflammability
2.7	2400	7000	White	9	No

Table 5. *Chemical composition of marble powder (% by weight)*

SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	Na_2O	MgO
0.13	0.11	0.04	57.67	0	0.05	0.17

Table. 6. *Chemical and mineralogical compositions of the various cements (% by weight)*

Elements	CEMI/42.5	CEMI/42.5 +5%PM	CEMI/42.5 +10%PM
SiO_2	21.63	20.52	19.33
Al_2O_3	4.42	4.19	3.97
Fe_2O_3	4.99	4.74	4.47
CaO	62.57	62.25	61.94
K_2O	0.33	0.31	0.30
Na_2O	0.15	0.13	0.13
C_3S	55.78	56.12	57.95
C_2S	25.20	24.97	24.14
C_3A	3.28	3.09	2.97
C_4AF	15.17	14.92	14.01

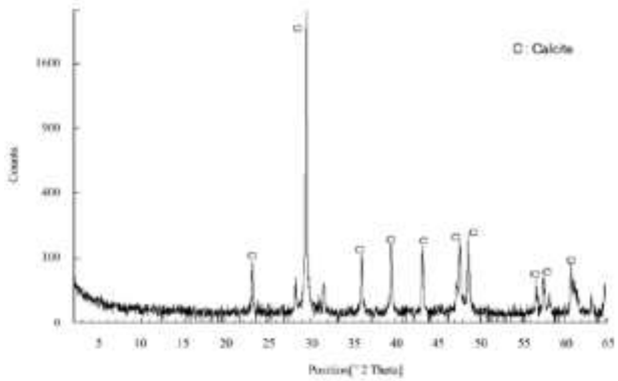

Figure 1. *X-ray diffraction diagram of marble (kα Cu radiation)*

II.4. Concrete formulation

Several methods are proposed among which the simplified practical method known as the "Dreux Gorisse" method [21], it allows to define in a simple and fast way a formula of composition well adapted for the concrete studied but that only a few wastes of tests and the making of the test pieces will make it possible to adjust the composition to be adopted definitively according to the desired qualities and the materials actually used. For a current work, we have chosen the following essential parameters:
- 0/15 concrete and therefore the maximum dimension of aggregates: D = 16.00 mm.
- The desired characteristic resistance: fc28= 30MPa.
- The desired workability is characterized by a cone slump: A= 11cm (very plastic concrete): This

choice is guided to facilitate handling by means of the ICAR rheometer.
- Water/Binder ration = 0.50
- Cement dosage (Kgm^{-3}) = 400

Table 7 presents the basic data of the formulation and table 8 shows the composition of $1m^3$ of concrete.

Table 7. *Basic data of the concrete formulation*

Designation	Gravel 8/15	Gravel 3/8	Sand 0/5
Apparent volumic mass	1.56	1.54	1.74
Absolute volumic mass	2.57	2.71	2.61
Sand equivalent	/	/	85.30
Finesse module	/	/	2.20

Table 8. *Concrete composition*

Component	(%)	Composition of $1m^3$ of concrete (Kg)
Gravel 8/15	45	805
Gravel 3/8	15	283
Sand 0/5	40	727
Cement	-	400
Water	-	216
Total	-	2431

II.5. Concrete making and testing

Five (05) types of concrete were manufactured:
- A control concrete based on CEMI/42.5 cement noted BT.
- A concrete based on CEMI/42.5+5%PM (Blaine fineness of marble powder $2400cm^2/g$) noted BPM5% SSB24.
- A Concrete based on CEMI/42.5+5%PM (Blaine fineness of marble powder $7000cm^2/g$) noted BPM5% SSB70.
- A Concrete based on CEMI/42.5+10%PM (Blaine fineness of marble powder $2400cm^2/g$) noted BPM10% SSB24.
- A Concrete based on CEMI/42.5+10% PM (Blaine fineness of marble powder $7000cm^2/g$) noted BPM10% SSB70.

The concrete was spoiled in a vertical-axis concrete mixer with a capacity of 80 liters. To characterize the flow behavior of the concrete, the ICAR rheometer was used (Figure 2). This device aims to induce a cylindrical symmetry flow confined concrete in a tank by the imposition of a rotational speed on a mobile, it measures in return the resistance that the concrete opposes this movement. It is thus possible to construct curves connecting the two absolute rheological quantities of concrete (the velocity gradient $\dot{\gamma}(s^{-1})$ and the shear stress τ (Pa)). The curves can be modeled in a more or less complex way. The rheological model of Bingham is the most commonly used in the field of cementitious materials according to Tattersall & Banfill [22] and Ferraris & De Larrard [23]. This model is used for fluids that are characterized by the presence of a yield stress. The yield stress (τ_o) (Pa) is defined as the minimum stress to exert to set the concrete in motion and the plastic viscosity ηPl (Pa.s) is the slope of the shear stress curve versus the velocity gradient.
Bingham's model describes the flow of concrete using the equation: $\tau = \tau_0 + \eta\dot{\gamma}$

Figure 2. *The ICAR Rheometer*

The concretes were placed in molds $10x10x10cm^3$ for compression tests and prismatic molds $7x7x28cm^3$ for the four-point bending tests. The molds were consolidated by vibration and then covered with plastic sheets at a temperature of 20±1°C and a relative humidity of 99%. After 24±1h, the specimens were demolded and stored at laboratory temperature (≈ 20°C) in tap water until the test period (3 days, 7 days, 28 days and 60 days). The four-point bending tests were performed with a loading rate of 0.5 mm/min. The compression tests were carried out with a loading rate of 0.25 mm/min.

III. Results and discussion

III.1. Effect of the marble fineness on the rheology of fresh concrete

By examining figure 3, we note, on the one hand, the substitution of CEMI/42.5 cement with marble powder at the rate of 5% and 10% with the two Blaine fineness, $2400cm^2/g$ (powder collected from marble works) or well $7000cm^2/g$ (milled with a

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ball mill) has no influence on the viscosity of the concrete which is practically the same for all concretes (an insignificant reduction in the viscosity which varies between 29.3 Pa.s and 30.4 Pa.s) (Figure 4).

On the other hand, the yield stress (τ_o) increases substantially when the level of marble powder is 10%. A great fineness of the marble powder ($7000cm^2/g$) remarkably increases the yield stress (τ_o) which goes from 468Pa of a control concrete without addition to 716Pa. The partial replacement of the cement with 5% of marble powder with a fineness of $2400cm^2/g$ has a negligible effect on the yield stress (τ_o) of the concrete which recorded a value of 493Pa (Figure 5).

These results are in agreement with those of Zhang & Han [3] which showed that the yield stress (τ_o) increases with the amount of ultrafine addition incorporated while the viscosity of the paste varies with the nature and the amount of addition.

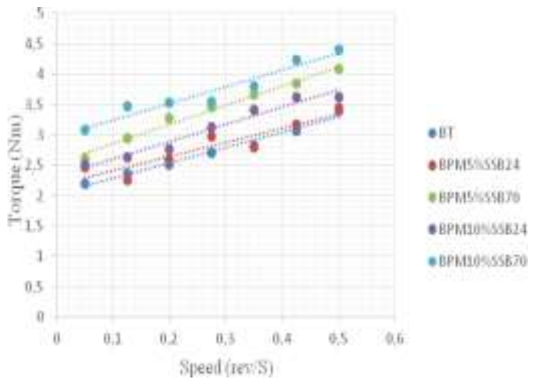

Figure 3. *Flow Curve of different types of concrete*

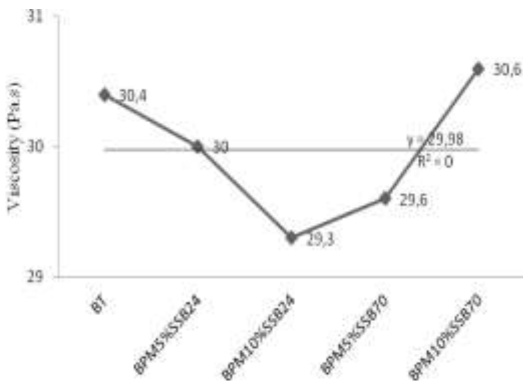

Figure 4. *Evolution of the viscosity of the different types of concrete*

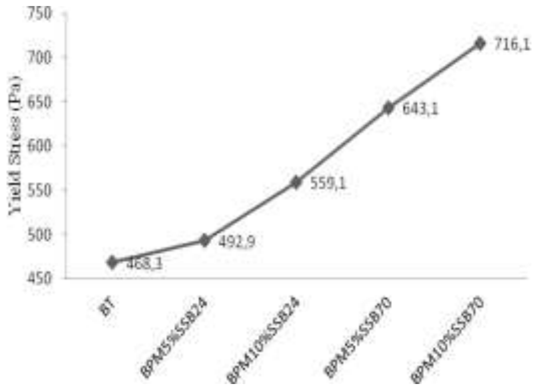

Figure 5. *Evolution of the shear stress of the different types of concrete*

III. 2. Effect of the marble fineness on the rheology of concrete in the hardened state

Four-point flexural tensile strength and concrete compression were determined at different time intervals (3, 7, 28 and 60 days) to determine short-term and long-term strengths. The results are reported in Figures 6 and 7.

The compressive strengths of different types of concrete are very interesting and that at all deadline. The concretes reached very important performances after 60 days (more than 60MPa). The addition of 5% or 10% of marble powder with a Blaine fineness of $2400cm^2/g$ slightly decreases the resistance during the first seven (07) days, but the resistances improve significantly after 28 days (about 52MPa for the concrete with the addition of 5% marble powder and 47MPa for concrete with the addition of 10% marble powder).

By grinding the marble powder to a Blaine fineness of $7000cm^2/g$, the strengths of the concrete with 5% addition of marble powder exceed those of control concrete without addition and at all maturities. Resistance of concrete with 10% addition of marble powder improves significantly but is lower than that of control concrete or concrete with 5% addition.

In a previous study [20], it has been shown that the density of concretes is notably increased by the addition of quasi-inert fillers, marble calcite. This explains the high performance recorded by the concrete.

Flexural strengths evolve in the same way as compressive strengths. Concretes with addition of

5% marble powder with a Blaine fineness of $2400cm^2/g$ have resistances comparable to those of control concrete without addition. Resistances are much better if the marble powder is well ground ($7000cm^2/g$).
Concretes with 10% addition of marble powder have acceptable strengths but are slightly lower than control concrete or concrete with 5% addition.

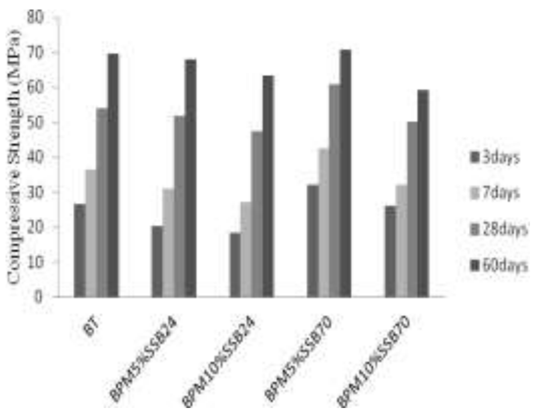

Figure 6. *Evolution of the compressive strength of different types of concrete*

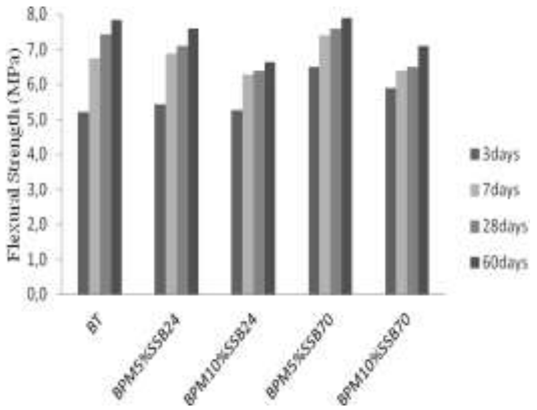

Figure 7. *Evolution of the compressive strength of different types of concrete*

IV. Conclusions

The results obtained show that the formulation of cement-based concrete with the addition of marble powder makes it possible to manufacture economic (energy-saving) and ecological concretes (preservation of natural resources and protection of the environment). Concrete retains its long-term high performance mechanical properties and acceptable rheological characteristics in the fresh state. The marble powder used is waste from the cutting plants, its Blaine fineness is $2400cm^2/g$.

The results show that the partial substitution of the cement with 5% of marble powder with a Blaine fineness of $2400cm^2/g$ has no effect on the rheological characteristics of the concrete in the fresh state: the yield stress (τ_o) increases very slightly (468Pa and 493Pa for control concrete without addition and cement-based concrete with addition of 5% marble powder, respectively), on the other hand, the viscosity is practically the same for both concretes (about 30Pa.s). The compressive strength decreases slightly during the first seven (07) days, but improves significantly after 28 days (about 52MPa). Grinding the marble powder to a fineness of $7000cm^2/g$, the yield stress (τ_o) increases remarkably to reach 643Pa but the viscosity remains stable. The compressive strength exceeds that of control concrete without addition and at all maturities (3, 7, 28 and 60 days).

The increase in the rate of replacement of the cement by the 10% marble powder affects the yield stress (τ_o) which increases remarkably (559Pa for a Blaine fineness of $2400cm^2/g$ and 716Pa for a Blaine fineness of $7000cm^2/g$), the viscosity is practically the same but the compressive strengths are important (47MPa for a Blaine fineness of $2400cm^2/g$ and 50MPa for a Blaine fineness of $7000cm^2/g$ at 28 days) but these resistances are lower than those of cement-based concrete with addition of 5% of marble powder.

Flexural strengths evolve in the same way as compressive strengths. Concretes with addition of 5% marble powder with a fineness of $2400cm^2/g$ have resistances comparable to those of control concrete without addition. Resistances are much better if the marble powder is well ground ($7000cm^2/g$). Concretes with 10% addition of marble powder have acceptable strengths but are slightly lower than control concrete or concrete with 5% addition.

These results are particularly interesting and join the very current issues on the optimization of compound binders. It can be said that the optimum in marble powder should be equal to 5% and this is quite comparable to the results of Menendez et al., Carrasco et al., and De Weerdt et al., [9, 24, and 25] obtained with calcareous filler.

With 5% of marble powder and without extensive grinding ($2400cm^2/g$), concrete retains its rheological characteristics in the fresh state and its mechanical properties in the hardened state.

The use of cements, containing marble waste, can lead to the energy saving and reduction of CO_2 emission without worsening of the mechanical properties of cement.

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