CONTRIBUTION TO THE STUDY OF HIGH-COMPACT FLUID CONCRETES: FORMULATIONS AND CHARACTERIZATIONS

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ABSTRACT

A more ambitious study on the formulations of high-compact fluid concretes was shown to us. The use of other concrete components such as dolomite, cipolin, new aggregates and superplasticizers differentiates the fluid concretes in this study from those of conventional ordinary concrete.

The objective of this work was therefore to give clear answers to the search for the best composition of fluid concretes with the important presence of the two types of fines, the two types of sand and the two types of superplasticizers in this composition. The formulations of fluid concretes are distinguished by a greater volume of paste (related to the methodology used), the use of superplasticizers in greater quantities in relation to the cement. All these formulations are then characterised using specific tests to verify their ability to comply with the recommendation and standard for fluid concretes.
The determination of these characteristics of the raw materials also allowed us to choose the formulation methods. The DREUX GORISSE method was used for the formulation of ordinary concretes, which are control concretes. The method of absolute volumes is also carried out at first sight, in order to have a pre-formulation adapted to fluid concretes.
A characterization of fluidity and capacity of passage between reinforcements at the concrete scale provides physical bases for the phenomena involved in the transition between an ordinary consistency concrete and a fluid concrete, and brings a better understanding of the formulation modifications and their consequences.

Keyword: *Concretes, Superplasticizers, Cipolin, Dolomite, Fillers, Formulation, Compactness, Compressive strength, Compactness, Shrinkage, Workability, Durability.*

1. INTRODUCTION

Fluid concretes are concretes capable of flowing under their own weight, whatever the containment of the medium, and remain homogeneous during flow (absence of dynamic segregation) and in place (absence of static segregation). Fluid concretes have been developed over the last twenty years or so. They are still currently classified as new ranges of concretes because more and more attention is paid to their formulation [1].

The specificity of fluid concretes compared to traditional concretes lies in the fact that they are extremely fluid and do not require vibration to be used. Compacting under the effect of their own weight, they can be poured in areas with a high level of reinforcement or in areas of complex and difficult to access architecture [2].

Different formulations are adopted in order to be able to compare the fluidity, durability, mechanical performance and cost price of concrete.

The main objective of this work is to formulate fluid concretes using the absolute volume method. In this case, we tried to adopt new formulas with raw materials that will specify these fluid concretes.

2. RAW MATERIAL CHARACTERIZATIONS [3][4]

2.1 Cement

Throughout the experiment, MANDA CEM II class 42.5 cement from HOLCIM Madagascar was used. It is sold in all hardware stores in a 50 Kg bag. Its relative density is 3,1 and its Blaine SSB surface is equal to 3400 [cm2/g] and a beginning of setting of 169 [mn]. Its Alumina Module (AM), Silica Module (SM) and Lime Module (LM) values are 1.70, 1.85 and 92.55 respectively.

2.2 Aggregates

The quarry sands Sc used, come from the quarry of the company SCB of the RAJABALY group which is located on the RN4 of the PK 18 located in Anosiala - District of Ambohidratrimo.
For the river sands, one comes from the Ikopa Sr1 river taken from Anosizato, near the Silver Star Hotel. The other comes from the Sisaony Sr2 river at the entrance of the Ambatofotsy bridge in the direction of Ampitatafika.
Crushed gravel g1 class 5/12.5 from the Vontovorona artisanal quarry and crushed gravel g2 class 5/15, G class 5/25 from the open-cast quarry operated by the SCB company (PK18 RN4) are used. These pebbles have a more or less concave shape. They come from the crushing of a granitic rock. The g2 (5/15) and G (5/25) gravels have a coefficient of Los Angeles LA = 25 in granular class 10/25. They are respectively of the category 0.19 and 0.20 (volumetric coefficient). The shapes are therefore tolerable. The gravel from the Vontovorona g1 artisanal quarry has a coefficient of Los Angeles LA = 30, less resistant to shocks than the gravel from the SCB quarry.
The river sands Sr1 and Sr2 used have a modulus of fineness equal to 2.9 and 3.1 respectively. These are coarse sands. The modulus of fineness of the Sc quarry sand is 2.3; a little fine compared to the river sands. These are spread sands (Cu>2), tolerable in the formulation. The aggregates are characterized by their absolute densities σ [T/m3] and its sand equivalents ES [%] (table 1).

Table -1 : Absolute densities σ [T/m3] and ES sand equivalents [%] of aggregates

Sr1		Sr2		Sc		g1	g2	G
σ [T/m^3]	ES[%]	σ [T/m^3]	ES[%]	σ [T/m^3]	ES[%]	σ [T/m^3]	σ [T/m^3]	σ [T/m^3]
2,578	76	1,463	2,627	1,505	2,654	2,618	2,613	2,608

Their sieve size analysis is shown in figure

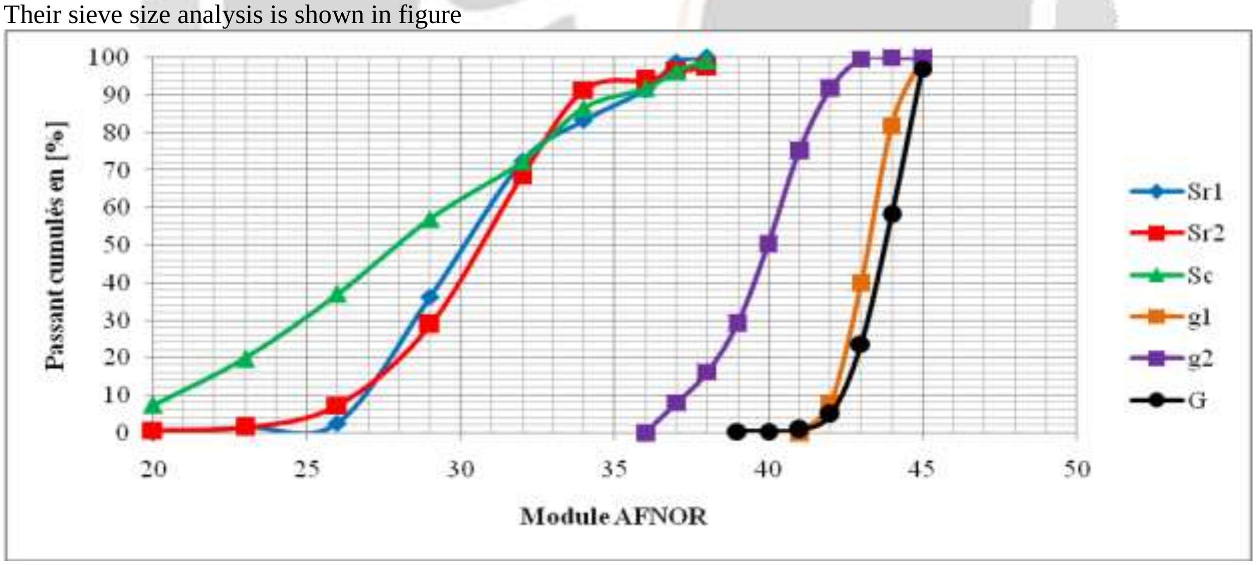

Fig - 1: Particle size curves of aggregates

2.3 Les fillers

2.3.1 Filler cipolin (F_{Cp})

The white cipolin rock from the HOLCIM quarry in IBITY is finely crushed by the ball mill for three days continuously in order to obtain great fineness. The mill used is the ball mill of the CNRIT laboratory.

The cipolin filler used as an additive in concrete is obtained by sieving on a 50 µm opening sieve. The cipolin filler has an absolute density of 2.846 [T/m3] and a Blaine SSB surface area of 3500 [cm2/g]. The major chemical elements in the cipolin filler are given in Table 2.

Table -2: Major chemical elements in cipolin

SiO2 [%]	Fe2O3 [%]	Al2O3 [%]	CaO [%]	MgO [%]	Na2O [%]	K2O [%]	SO3 [%]	P.F. [%]
10,75	0,1	0,69	50,38	0,53	0,2	0,13	0,11	35,23

2.3.2 Filler dolomie (F_D)

Dolomite is classified geologically as detrital rock and rocks of hydrothermal origin (precipitation from marine waters).

The already pulverized dolomite produced by PROCHIMAD from the Ihenikenina quarry is marketed in the form of 50 kg bags and is designated "Dolomite D40". ($D \leq 40$ µm). Its absolute density is 2.721 [T/m3] and its Blaine SSB surface area is 3300 [cm2/g]. The major chemical elements in the Dolomite filler are given in Table 3.

Table -3: Major Chemical Elements in Filler Dolomite (FD)

SiO2 [%]	Fe2O3 [%]	Al2O3 [%]	CaO [%]	MgO [%]
15,6	0,2	1,6	30,8	22,6

2.4 Water

JIRAMA tap water is used for mixing concrete. The water must be free of organic matter as this reduces the mechanical strength of the concrete. The characteristics of JIRAMA (JIRO SY RANO MALAGASY) water are given in the following table 4.

Table - 4 : Characteristics of JIRAMA water

Insoluble	Dissolved matter [mg/l]	Alkali carbonates + bicarbonates [%]	Sulphates SO3	Sulphites S [%]	Sugars [%]	P2O3[%]	NO3[%]	Zn [%]
0	0,0004	0,0028	0	0	0	0	0	0

2.5 Superplasticizers

2.5.1 Sika ®viscocrete®tempo12 (Sp_1)

Sika®ViscoCrete®Tempo 12 is a versatile, high water-reducing superplasticizer that improves stability, limits concrete segregation and makes formulations less susceptible to water and component variations.

The product has been supplied by MADECASSE who is the authorized distributor of Sika products in Madagascar and its characteristics and application conditions are shown in Tables 5 and 6 below.

Table -5: Characteristics of the superplasticizer sika ®viscocrete®tempo12

Aspect	Density	pH	Content Na2O eq-	Dry extract	Content Cl-
Light brown liquid	$1,06 \pm 0,01$	6 ± 1	$\leq 1\%$	$30,2 \pm 1,3$ %	$\leq 0,1$ %

Table -6:Application conditions for sika ®viscocrete®tempo12 superplasticizer

Typical range of application	Recommended range of use
0.4 to 1.5% of the weight of the cement	0.2 to 3% of the weight of the cement depending on the fluidity and performance required

2.5.2 Le rhéobuild 561 (Sp_2)

Rheobuild 561 is also a water-reducing superplasticizer that significantly improves the properties of both fresh and hardened concrete. Rheobuild 561 superplasticizer was supplied by the company BATPRO which is the authorized distributor of BASF products in Madagascar.

The characteristics and application conditions of Rheobuild 561 are shown in tables 7 and 8 below.

Table -7: Characteristics of Rheobuild 561 superplasticizer

Aspect	Density	pH	Content Na2O eq-	Dry extract	Content Cl-
Brown liquid	1,17 ± 0,03	8,5 ± 1,5	≤ 1%	-5°C	≤ 0,1 %

Table -8: Application conditions for Rhéobuild superplasticizer

Typical range of application	Recommended range of use
0.4 to 1.5% of the weight of the cement (i.e. 0.34 L to 1.28 L per 100 Kg of cement)	In case of frost, heat the product to a temperature close to + 30°C and stir mechanically. Prohibit stirring with compressed air.

4. CONCRETE FORMULATIONS

4.1 Formulations for Ordinary Concrete (BO)

Ordinary concretes without the addition of fines and admixtures were first formulated so that these control concretes could be compared to fluid concretes. This is to show that fluid concrete will have easier workability, higher mechanical strength and better durability than regular concrete [5].

BO1 = Sr1 + g1 + E+C with a cement dosage fixed at 400 Kg/m3

BO2 = Sr2 + g2 +G+ Sc + E + C with a cement dosage fixed at 350 Kg/m3

When characterizing the materials, the sands Sr2 and Sc; the gravels g2 and G present more favorable characteristics compared to Sr1 and g1. For this reason, the cement dosage is reduced to 350 Kg/m3 for BO2.

The method used for the formulation of ordinary BO1 and BO2 concretes is the Dreux Gorisse method. The dosages of each constituent of BO1 and BO2 found by this method are given in table 9 below.

Table -9 : Doses of each constituent of BO1 and BO2 in one cubic metre

BO1				BO2					
C[Kg]	E[L]	Sr1[Kg]	g1[Kg]	C[Kg]	E[L]	Sc[Kg]	Sr2[Kg]	g2[Kg]	G[Kg]
400	220	752	992	350	203	262	491	292	815

4.2 Results of BO1 and BO2

The theoretical 28-day compressive strength of 25 MPa for BO1 is not achieved; although the cement dosage is high (Table 10). Many parameters can be attributed to the fact that the diameter of the chippings used is very small, and its Los Angeles coefficient is relatively low compared to chippings from the SCB quarry. The water dosage is also 220 litres per cubic metre (a high water dosage). In the case of the slump test, the excate value of 8 cm is reached.

Table -10 : Slump and compressive strength results of BO1 by the DREUX GORRISSE method

ST [cm]	AGES [Days]	N ° OF THE TEST	DENSITY	CHARGE [KN]	Rc en [MPa]	ARITHMETICAL AVERAGE OF Rc [MPa]
8,3	7	(1)	2,410	323,95	16,12	16,04
		(2)	2,408	320,13	15,93	
		(3)	2,431	322,94	16,07	
	28	(4)	2,421	486,52	24,21	23,2
		(5)	2,432	440,91	21,94	
		(6)	2,400	471,25	23,45	

For BO2, a greater dispersion of the compressive strength of concrete at young ages, at 7 days, was noted; however, at 28 days, this dispersion of strength is generally low. The resistance obtained experimentally at 28 days corresponds well to that predicted by the theoretical resistance of 26 MPa (Table 11).

The formulation adopted for BO2 is therefore acceptable. And, it has been proved that the materials used for BO2 formulation are good qualities even if the cement dosage is reduced to 350 kg in one m3 of concrete.

Table –11 : Results of slump and compressive strength of BO2 by the GORRISSE DRILL method

ST [cm]	AGES [Days]	N ° OF THE TEST	DENSITY	CHARGE [KN]	Rc en [MPa]	ARITHMETICAL AVERAGE OF Rc [MPa]
8,1	7	(1)	2,400	395,57	19,68	19,96
		(2)	2,407	408,23	20,31	
		(3)	2,411	399,59	19,88	
	28	(4)	2,398	517,58	25,75	26,22
		(5)	2,400	535,46	26,64	
		(6)	2,403	528,03	26,27	

4.3 Formulation of BFL1 fluid concretes by the absolute volume method

The absolute volume method is used to determine the composition of mixtures whose total volume is specified upstream. Its qualities give it a character that is both precise and random, and it is the most suitable for research work. Knowing that a mixture of fluid concretes is usually composed of water, cement, sand, gravel, superplasticizers, and fillers. This method includes the volume of air trapped in the mixture.

VSr1 + Vg1 + VE +VC + VSp1 + Va + VFcp = 1000 L (1m3 of concrete)

The cement dosage is fixed at 400 Kg/m3 for BFL1. This aims to take as the refernce the ordinary concrete BO1

BFL1 = g1+Sr1+C+E+ Sp1+ Fcp with a cement dosage of 400 Kg/m3.

For BFL1, W/C = 0.55, G/S = 1 and Dmax = 12.5 mm. The dosage of superplasticizer SP1 is tattooed by varying the Filler Cipolin /Cement ratio (FcP /C) according to the indications in the data sheet.

The air volume Va of the concrete is about 5% (AFGC recommendations),

so Va = 50 L

$$\frac{Sr_1}{\sigma\ (Sr_1)}+\frac{Sr_1}{\sigma(g_1)}+\frac{E}{\sigma(E)}+\frac{C}{\sigma(C)}+\frac{Sp_1}{\sigma(Sp_1)}+\frac{F_{CP}}{\sigma(F_{CP})}+V_a=1000$$

However, the volume of concrete pastes is

$$V_{pates}=\frac{E}{\sigma(E)}+\frac{C}{\sigma(C)}+\frac{Sp1}{\sigma(Sp1)}+\frac{FC_P}{\sigma(FC_P)}+V_a \quad \text{[L/m3]}$$

The sand and gravel dosage is determined by

$$Sr1=g1=\frac{1000-V_{pates}}{\left(\frac{1}{\sigma(Sr1)}+\frac{1}{\sigma(g1)}\right)}$$

Therefore, following the absolute volume method for the determination of sand and gravel dosages with a ratio G/S =1, we have the following BFL1 formula presented in Table 12:

Table-12 : BFL1 fluid concrete formulas in 1 m3

SAND[Kg]	GRAVELS [Kg]	CEMENT CEM II-A-42,5 [Kg]	FILLER CIPOLIN [Kg]	SIKA VISCOCRETE TEMPO 12 [L]	WATER [L]
Sr1	g1	C	Fcp	Sp1	E
672	672	400	220	7	220

This formula gives the following results (Tables 13 and 14)

Table -13: shrinkage, porosity and compactness values of BFL1

BFL1		
shrinkage R [%]	Porosity P [%]	Compacity C [%]
0,17	4,34	95,66

Table-14: Results of slump and compressive strength of BFL1

ST [cm]	AGES [Days]	N ° OF THE TEST	DENSITY	CHARGE [KN]	Rc en [MPa]	ARITHMETICAL AVERAGE OF Rc [MPa]
18	7	(1)	2,356	373,58	18,59	20,98
		(2)	2,297	400,11	19,91	
		(3)	2,315	491,15	24,44	
	28	(4)	2,391	686,28	34,15	35,75
		(5)	2,386	739,53	36,8	
		(6)	2,351	729,48	36,3	

4.3 Formulation of BFL2 fluid concretes by the absolute volume method

BFL2 is obtained by mixing gavillons g2 class 5/15, G class 5/25, river sand Sr2, quarry sand Sc, cipolin filler Fcp, sika viscocrete superplasticizer tempo 12 (Sp1) and water. The cement dosage is reduced to 350 Kg/m3 following the BO2 reference.

BFL2 = g2+G+Sr2+Sc+C+E+ Sp1+ Fcp with cement dosage C = 350 Kg

The new formula of this concrete for the purpose of laboratory verification tests of the physical characteristics of the constituents is given in Table 15 below.

Table-15 : BFL2 fluid concrete formulas in 1 m3

SAND[Kg]		GRAVELS [Kg]		CEMENT CEM II-A-42,5 [Kg]	FILLER CIPOLIN [Kg]	SIKA VISCOCRETE TEMPO 12 [L]	WATER [L]
Sr2	Sc	g2	G	C	Fcp	Sp1	E
368	368	368	368	350	193	7	203

The results of this formula are set out in Tables 16 and 17 below:

Table-16: shrinkage, porosity and compactness values of BFL2

BFL2		
shrinkage R [%]	Porosity P [%]	Compacity C [%]
0,10	4,1	95,9

Table-17 : Results of slump and compressive strength of BFL2

ST [cm]	AGES [Days]	N ° OF THE TEST	DENSITY	CHARGE [KN]	Rc en [MPa]	ARITHMETICAL AVERAGE OF Rc [MPa]
16	7	(1)	2,298	399,39	19,87	19,86
		(2)	2,300	404,21	20,11	
		(3)	2,360	414,06	20,60	
	28	(4)	2,387	674,36	33,55	33,87
		(5)	2,395	690,23	34,34	
		(6)	2,295	677,97	33,73	

4.4 Formulation of BFL3 fluid concretes by the absolute volume method

For BFL3, the cipolin filler is replaced by the dolomite filler whose purpose is to compare the reaction of these fines in concrete. We have BFL3 = g2+G+Sr2+Sc+C+E+ Sp1+ FD. The formula is presented in the following table 18

Table-18 : BFL3 fluid concrete formulas in 1 m3

SAND[Kg]		GRAVELS [Kg]		CEMENT CEM II-A-42,5 [Kg]	FILLER CIPOLIN [Kg]	SIKA VISCOCRETE TEMPO 12 [L]	WATER [L]
Sr2	Sc	g2	G	C	FD	Sp1	E
368	368	368	368	350	193	7	203

The results obtained from this formula are presented in Tables 19 and 20 below.

Table-19 : shrinkage, porosity and compactness values of BFL3

BFL3		
shrinkage R [%]	Porosity P [%]	Compacity C [%]
0,16	4,7	95,3

Table-20 : Results of slump and compressive strength of BFL3

ST [cm]	AGES [Days]	N ° OF THE TEST	DENSITY	CHARGE [KN]	Rc en [MPa]	ARITHMETICAL AVERAGE OF Rc [MPa]
19	7	(1)	2,277	363,61	18,09	18,88
		(2)	2,312	390,74	19,44	
		(3)	2,270	384,31	19,12	
	28	(4)	2,263	586,32	29,17	29,58
		(5)	2,299	614,26	30,56	
		(6)	2,303	583,50	29,03	

4.5 Formulation of BFL4 fluid concretes by the absolute volume method

The Sika viscocrete superplasticizer tempo 12 is replaced by Rheobuild 561 and the Cipolin filler, sand and gravel are still kept (BFL3 = g2+G+Sr2+Sc+C+E+ Sp2+ FCP) whose objective is to follow the reaction of Rheobuild 561 superplasticizer in terms of its fluidity and compressive strength.

The formula for BFL4 fluid concrete and the results are shown in the following tables

Table-21 : BFL4 fluid concrete formulas in 1 m3

SAND[Kg]		GRAVELS [Kg]		CEMENT CEM II-A-42,5 [Kg]	FILLER CIPOLIN [Kg]	SIKA VISCOCRETE TEMPO 12 [L]	WATER [L]
Sr2	Sc	g2	G	C	FCP	Sp1	E
368	368	368	368	350	193	7	203

Table-22 : shrinkage, porosity and compactness values of BFL4

BFL4		
shrinkage R [%]	Porosity P [%]	Compacity C [%]
0,07	3,6	96,4

Table-23 : Results of slump and compressive strength of BFL4

ST [cm]	AGES [Days]	N ° OF THE TEST	DENSITY	CHARGE [KN]	Rc en [MPa]	ARITHMETICAL AVERAGE OF Rc [MPa]
18	7	(1)	2,383	384,71	19,14	19,67
		(2)	2,306	412,85	20,54	
		(3)	2,397	388,33	19,32	
	28	(4)	2,351	606,02	30,15	29,79
		(5)	2,349	596,97	29,70	
		(6)	2,311	593,55	29,53	

4.6 Formulation of BFL45fluid concretes by the absolute volume method

In the case of BFL5, dolomite filler and the superplasticizer Reobuild 561 are used.
BFL5 = g2+G+Sr2+Sc+C+E+ Sp2+ FD and we have the following formula and results

Table-24: BFL5 fluid concrete formulas in 1 m3

SAND[Kg]		GRAVELS [Kg]		CEMENT CEM II-A-42,5 [Kg]	FILLER CIPOLIN [Kg]	SIKA VISCOCRETE TEMPO 12 [L]	WATER [L]
Sr2	Sc	g2	G	C	FCP	Sp1	E
366	366	366	366	350	193	7	203

Table-25 : shrinkage, porosity and compactness values of BFL5

BFL5		
shrinkage R [%]	Porosity P [%]	Compacity C [%]
0,17	3,8	95,2

Table-26: Results of slump and compressive strength of BFL5

ST [cm]	AGES [Days]	N ° OF THE TEST	DENSITY	CHARGE [KN]	Rc en [MPa]	ARITHMETICAL AVERAGE OF Rc [MPa]
21	7	(1)	2,356	390,95	19,45	19,22
		(2)	2,297	384,51	19,13	
		(3)	2,315	383,31	19,07	
	28	(4)	2,391	526,82	26,21	26,71
		(5)	2,386	540,29	26,88	
		(6)	2,351	523,20	26,03	

4.7 Analysis and duscusion

The objective of the studies of BOs is only the mechanical resistance to compression, but the priority for the formulation study of BFLs is to give them a good behaviour in the fresh state (workability) and in the hardened state. At 28 days, these BFLs have high compressive strengths compared to BOs.

For BFL1. The use of a higher cement dosage (C= 400 Kg/m3) allowed us to obtain a fluid concrete with a slump of ST=18 cm with a compressive strength Rc = 35.75 MPa at 28 days. During its formulation, the addition of Sika viscocrete superplasticizer tempo 12 allows it to flow easily without segregation. BFL1 has good compactness. These results meet standards, but we found that the cement dosage is high. That is why we have formulated other BFLs with a cement dosage of C = 350 Kg/m3.

For the fluid concretes BFL2, BFL3, BFL4 and BFL5 with cement dosage C= 350 Kg/ m3, the mechanical compression tests at 7 days and 28 days on the concrete specimens give satisfactory results but a little weak compared to that of BFL1. This is quite normal as the cement dosage is dimunitive. The Abrams cone slump results of these concretes (BFL2, BFL3, BFL4, BFL5) are acceptable: these concretes are classified as S4( ) type concretes according to the NF EN 206-1 standard.

No air bubbles are found when the test specimens are immersed in cold water. These BFL are concretes with low porosity, low shrinkage and very high compactness.

The use of cipolin filler gives better results on compressive strength compared to dolomite filler. This is the case of BFL4 and BFL5: BFL4 has a good compressive strength compared to BFL5.

The superplasticizer rheobuild 561 only gives a high concrete workability time (BFL5). It acts as a water reducer but has very little effect on the mechanical strength of the concrete: the compressive strength of BFL2 obtained from cipolin filler and sika viscocrete tempo 12 is higher than the compressive strength of BFL4 obtained from cipolin filler and rheobuild 561. On the other hand, BFL4 (ST = 18 cm) has a better workability compared to BFL2 (ST = 16 cm).

For fluid concretes with higher compressive strengths, it is therefore preferable to use Sika viscocrete tempo 12 as a water-reducing superplasticizer and cipolin filler instead of dolomite filler as concrete admixture fines, because with this admixture and filler, the concretes are workable and more resistant in compression (BFL1, BFL2, BFL3, BFL4).

5. CONCLUSION

Laboratory tests on the characterization of raw materials have been carried out in order to know their nature, their physical and/or chemical characteristics.
We have shown that a fluid concrete has a better durability, a higher mechanical resistance and an easier workability than BO.
The reduction of the cement dosage at C = 350 Kg/m3, allows to obtain satisfactory results on the compressive strengths of BFL but a little lower compared to that of BFL1.
In general, BFLs obtained from cipolin filler have higher compressive strengths compared to BFLs obtained from dolomite filler. The superplasticizer rheobuild 561, compared to sikaviscocrete tempo 12, provides a longer handling time but is less effective in terms of strength gain.
Moreover, the costs for the production of the new BFLs (BFL2, BFL3, BFL4) are lower compared to BO and BFL1. BFLs bring a saving in vibration energy and a reduction in the number of workers. In short, the results on the new BFL formulations we have achieved open a new window on the optimization of BFLs and help their diffusion to all the players in concrete construction.

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