Self-compactibility of flowing sand-concrete containing dune sand and marble powder

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Abstract. This paper evaluates the self-compactibility of flowing sand-concretes (FSC) mixtures, incorporated various dune sand and marble powder contents, by testing flowability (determined by slump flow and v-funnel tests), passing ability (determined by L-box test) and segregation (determined by the visual stability index). The compressive strength at 28 days was also determined. Results show that the slump flow of all FSC mixtures lie between 450 and 840 mm, thus satisfying flowability according the recommendations of AFGC, except for the mixture made with 150 kg/m^3 of marble powder (with a slump flow of 450 mm). V-funnel flow time, T500 time and L-box ratio of all mixtures were about 1.7-3.8 s, 0.6-2.3 s and 0.5-0.93 respectively. These results indicate that FSC have a v-funnel time shorter than the range proposed by EFNARC recommendations (8-12 s). Despite lower v-funnel times, no visual stability loss has been observed for all studied mixtures (all mixtures have a visual segregation index of 0 and 1).

Key words: Flowing sand-concrete, dune sand, marble powder, self-compatibility.

1. Introduction

Sand-concrete is known with its advantage of using abundant sands in Saharan regions (such as dune sand), which has mechanical strength comparable to conventional concretes (Bédérina, 2005; Bouziani, 2011; Bouziani, 2012a). This advantage becomes extremely interesting when sand-concrete can reach certain fluidity in order to flow under its own weight and completely fills the formwork even in the presence of dense reinforcement, without the need of any vibration, whilst maintaining homogeneity. However, to design a proper flowing sand-concrete (FSC) mixture is not a simple task. Recent experimental investigations have been carried out in order to assess fresh and hardened properties of FSC (Bouziani, 2012b; Bouziani, 2013). The evaluation of self-compactibility of such concretes is a key issue in establishing the mix design method, to find out whether it could be appropriate for the site application.

At required levels, fresh self-compacting concrete must possess the following key properties (AFGC, 2008):

- Flowability
- Passing ability
- Stability

To achieve these properties, some of the basic requirements are for FSC mixtures to have high powder content and the incorporation of superplasticizer. The superplasticizer is necessary for producing a flowable mix, while mineral additions, such as marble powder, have a purpose, beside substituting a part of the cement, it propitiate the appropriate stability so that the self-compactibility is reached. In FSC design, the dosage and fineness of aggregates have an important influence on quality of fresh and hardened properties. Bouziani et *al.* (2012a) have found that dune sand is a useful component in optimizing the particle size distribution of river sand and thereby increasing flowability and mechanical properties of the FSC mixes.

In this study, two series of seven FSC mixtures were produced. The self-compactibility of these mixtures was investigated by various tests (mini-slump, slump flow, T500 time, v-funnel flow time, visual stability index and L-box). The mechanical compressive strength at 28 days was also determined.

2. Experimental program

2.1. Materials

An ordinary Portland cement (CEM I 42.5) and a marble powder (MP) were used. The chemical and physical properties of cement and MP are given in Table 1. The sand used was a mixture of natural river sand (RS) and dune sand (DS). Selected sands are subjected to grain size distribution analysis as per XP P 18-540 standard (AFNOR, 1997). The set of sieves are taken from 5 mm to 0.08 mm with aggregate and sieve shaker subjected to vibration for 15 minutes. The particle size gradation obtained thorough sieve analysis method and physical properties of DS and RS are grouped in Table 2. The obtained results show that DS is characterized by its fineness and cleanness. A polycarboxylate-type third generation high range water reducing superplasticizer (SP) conforming to the NF EN 934-2 standard (AFNOR, 2002) was used. The solid content, pH and specific gravity are 30 %, 6 and 1.07 respectively.

Table 1. Chemical composition and physical properties of cement and MP.

Compounds (%)	Cement	MP
CaO	63.55	53.1
SiO_2	23.24	0.54
Al_2O_3	4.72	0.29
Fe_2O_3	3.84	0.21
MgO	0.65	0.84
K_2O	0.4	0.05
SO_3	0.28	0.03
Na_2O	0.1	/
Cl	/	0.1
Free CaO	0.52	/
Insoluble residue	0.5	0.4
Loss of ignition	2.15	44.4
Specific density	3.1	2.7
Blaine Surface (cm^2/g)	3950	3200

Table 2. Sieve analysis and physical properties of used sands (DS and RS).

Sieve size (mm)	Cumulative passing (%)	
	DS	RS
5	100	99.5
4	100	97.09
2.5	100	83.56
1.25	99.92	63.27
0.63	98.09	34.85
0.315	82.86	13.65
0.16	19.36	2.44
0.08	1.63	0.84
Specific density	2.7	2.56
Fineness modulus	1	3.03
Sand equivalent	91	87.7
Absorption (%)	2.18	0.59
Moisture content (%)	1	0.33

2.2. Mixtures proportions

Based on the results of Bouziani et *al*. (2011, 2012a) Seven FSC mixtures were designed in order to obtain an adequate fluidity and stability in fresh state and a good mechanical strength in hardened state. In first, four mixtures were prepared in which the sand was composed of a binary blend of RS and DS, with different proportions of DS (0, 10, 20 and 30 % by weight of total sand), while keeping a constant marble powder (MP) content of 250 kg/m^3. Then, three mixtures were prepared in which the DS content was kept constant (10 %), while varying the MP content (150, 200, 250 and 300 kg/m^3). The water/powder ratio (W/B) and the dosage of superplasticizer (SP) were kept constant (W/B = 0.43 and SP = 1.6 %). All mixtures were prepared with constant cement content of 350 kg/m^3. The compositions of FSC mixtures are presented in Table 3.

Table 3. Compositions of prepared FSC mixtures.

Mix N°	DS		RS	MP	W/B	Water	SP	
	%	kg/m^3	(kg/m^3)	(kg/m^3)		(l/m^3)	(%)	(kg/m^3)
FSC1	0	0	1500	250	0.43	254	1.6	5.6
FSC2	10	150	1350	250	0.43	254	1.6	5.6
FSC3	20	300	1200	250	0.43	254	1.6	5.6
FSC4	30	450	1050	250	0.43	254	1.6	5.6
FSC5	10	150	1350	150	0.43	211	1.6	5.6
FSC6	10	150	1350	200	0.43	232.6	1.6	5.6
FSC7	10	150	1350	300	0.43	275.6	1.6	5.6

2.3. Testing procedure

The mixing sequence consisted of homogenizing sands, cement and MP in a free fall non-tilting horizontal axis type laboratory mixer for three minutes. Next, half of the mixing water was added and the mixture was mixed for three minutes. Then, SP and the remaining water were added and mixing was continued for another three minutes. For determining the self-compactibility of FSC, mini-slump flow, slump flow, T500 time, v-funnel flow time and L-box tests were performed. The tests were performed in accordance with AFGC (2008) and EFNARC recommendations (EFNARC, 2002). Due to the finesses of aggregates in FSC, the stability of fresh mixtures was assessed by visual stability index (VSI) (Daczko, 2002). This method provides a numerical rating (from 0 to 3) to evaluate the stability of flowing concrete mixtures, based only on a visual observation.

3. Results and discussion

Test results on the effect of DS and MP on mini-slump and slump flow are presented in Fig. 1 and Fig. 2 respectively. The results of slump flow test to rate the fluidity are of 450–850 mm at all mixtures, which satisfied the range of standard capacity of self-compacting concrete per the three class rating of AFGC (2008), except for the mix FSC5 (made with 150 of MP kg/m^3).

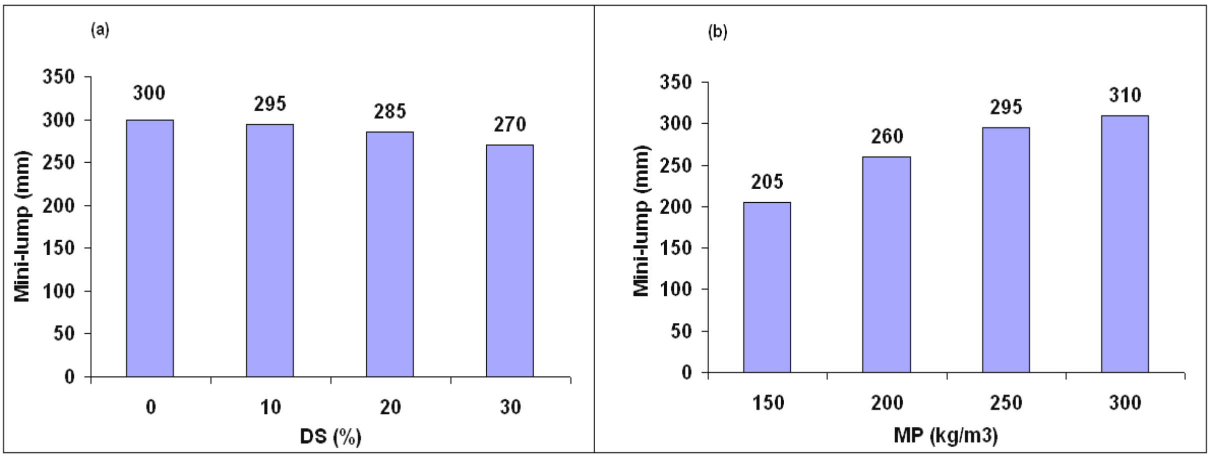

Fig 1. Mini-slump for FSC: (a) Effect of DS, (b) effect of MP.

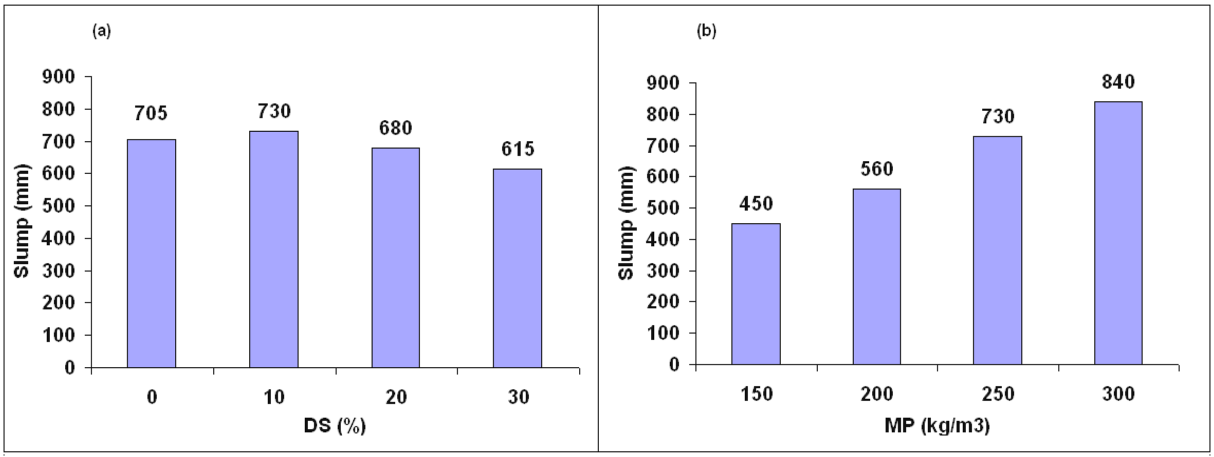

Fig 2. Slump flow for FSC: (a) Effect of DS, (b) effect of MP.

The effect of MP content on slump flow seems to be more dominant than the effect of DS replacement ratio. Examples of slump flow test for FSC2 and FSC5 mixtures are presented in Fig. 3. From the results in Fig. 2, it can be seen that the slump flow is higher for the mix FSC2 than the other mixes. This is may be a result of the high compactness of aggregates at 10 % of DS, which results in a smaller volume of void to be filled and hence larger amount of excess paste is gained for lubrication purpose (Bouziani, 2012a). Results in Fig. 2 (b), show also that the slump flow of FSC will increases with the increase of MP amount.

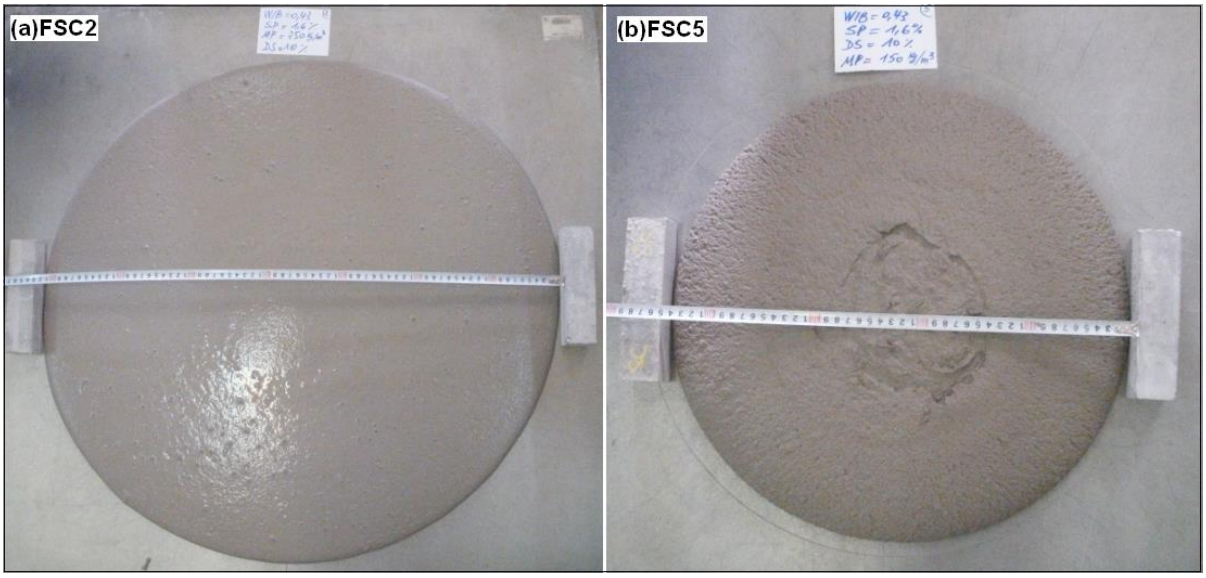

Fig 3. Examples of slump flow test: (a) FSC2, (b) FSC5.

Many researchers have used the mini-slump as indicator of slump flow of highly flowable concrete mixtures. Edmasatu has suggested that values between 250 and 280 mm for mini-slump will produce successful self-compactibility. However, Chai suggested a minimum mini-slump value of 300 mm (Domone, 1999).

The relationship between the results of mini-slump and slump flow of FSC is presented in Fig. 4. This figure shows that there is a good relationship between mini-slump and slump flow (with R^2 = 0.91). From these results, it can be concluded that mini-slump values between 250 and 330 mm are sufficient to predict a slump flow ranged between 550 and 850 mm of FSC (interval recommended by AFGC (2008)).

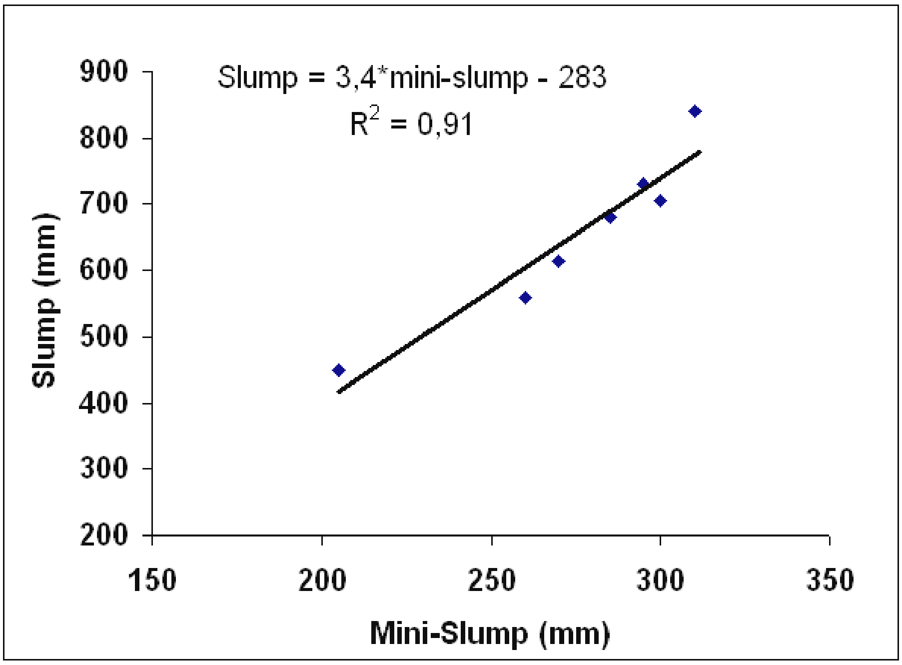

Fig 4. Correlation between mini-slump and slump test results.

With the same test, the time T500 is also measured when the mixture is slumping until it reached 500 mm of slump flow. As shown in Fig. 5, the mix FSC2, with 10 % of DS show the minimum value of T500 (0.6 s). This measure of T500 could not be carried out for the mixture FSC5 because it did not reach a slump flow of 500 mm (Fig. 3(b)).

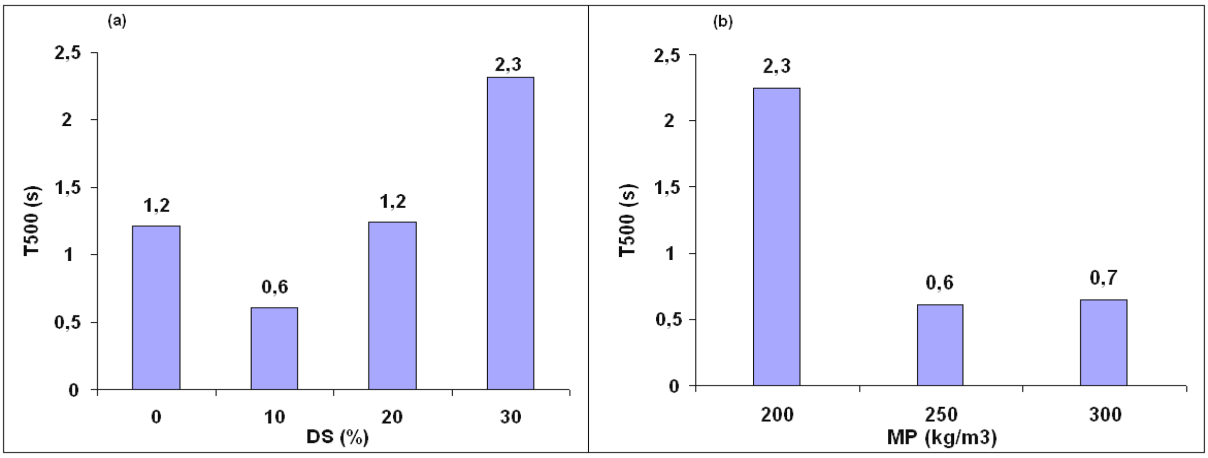

Fig 5. T500 time for FSC: (a) Effect of DS, (b) effect of MP.

The effect of DS and MP contents, on v-funnel time is presented in Fig. 6. These results show that FSC mixtures have a v-funnel time ranged between 1.7 and 3.8 s. It can be observed that v-funnel times of all FSC mixtures are outside the range of 8–12 s, specified by EFNARC recommendations. It is considered that a mixture having a v-funnel time below 8 s has a potential of stability loss. Conversely, in this experimental study no visual stability loss has been observed at all mixtures (all mixture have a VSI of 0 and 1). Such results seemed to be caused by the absence of coarse aggregate in FSC, which allowing rapid deformability without segregation. It should be noted that higher T500 and v-funnel times may reduce the acceptability of mixtures for self-compactibility (Felekoğlu, 2007).

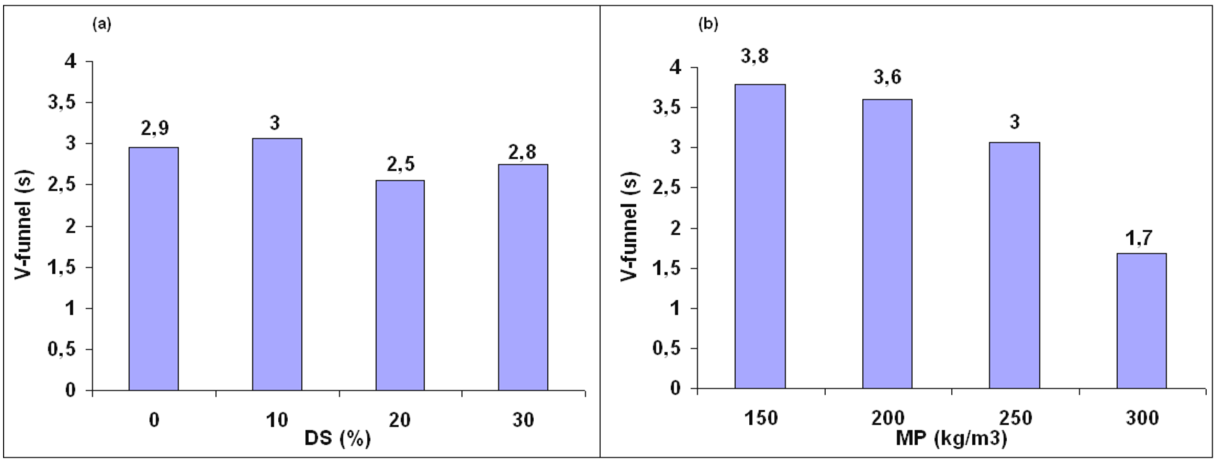

Fig 6. V-funnel time for FSC: (a) Effect of DS, (b) effect of MP.

The determined L-box ratios H2/H1 of FSC mixtures are presented in Fig. 7 (where H1 is the high of FSC, measured inside the vertical part and H2 is the high measured in the extremity of the horizontal part of L-box). It can be observed that studied mixtures have a good filling ability, except for the mixtures FSC4, FSC5 and FSC6 which have L-box ratios lower than 0.8. Due to the absence of coarse aggregate in FSC, it can be said that the observed blocking is caused by the high viscosity of FSC mixtures. Examples of L-box test for FSC2 and FSC5 mixtures are presented in Fig. 8. The decrease in L-box ratio of the mixture FSC4 (made with 30 % of DS) is due to the large finesses of DS and to their need for water (Absorption coefficient of DS = 2.18%). For the mixtures FSC5 and FSC6, the decrease in L-box ratios can be reported to the low dosages of MP.

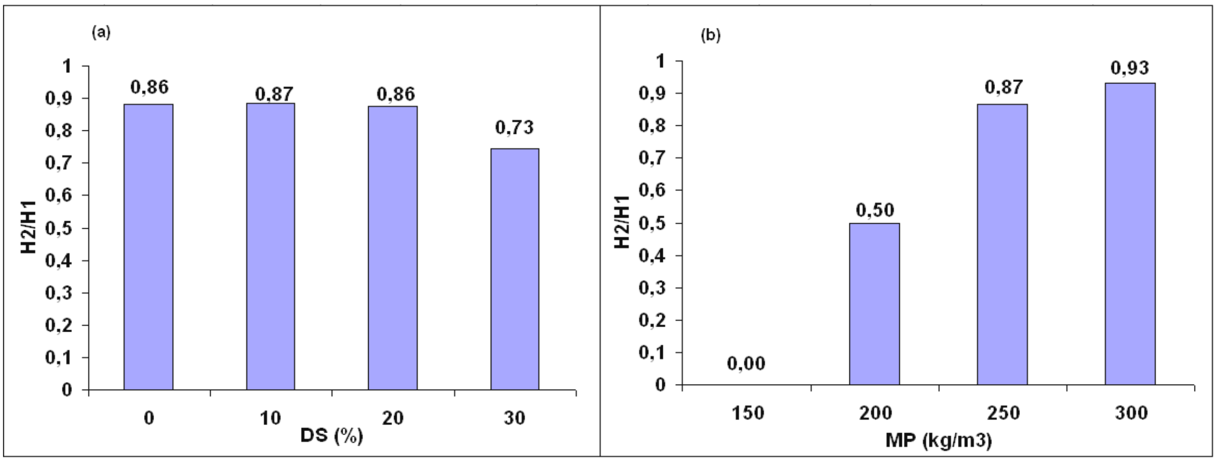

Fig 7. L-box ratios for FSC: (a) Effect of DS, (b) Effect of MP.

Fig 8. Examples of slump flow test: (a) FSC2, (b) FSC5.

Fig. 9 represents the results of testing hardened FSC for the compressive strength at 28 days. As shown in this figure, it can be seen that for a constant MP content of 250 kg/m^3, the DS has an optimal content (at 10 %) for which the compressive strength at 28 day is better. Such result seems to be offered by the high compactness of aggregates at 10 % of DS. It can be also seen that for constant DS content of 10 %, the compressive strength at 28 day decreases (from 41 to 37 MPa) with the increase of MP content (from 150 to 300 kg/m^3). For a constant water/binder ratio, the reduction of compressive strength may be caused by the increase of water/cement ratio with the increase of MP content.

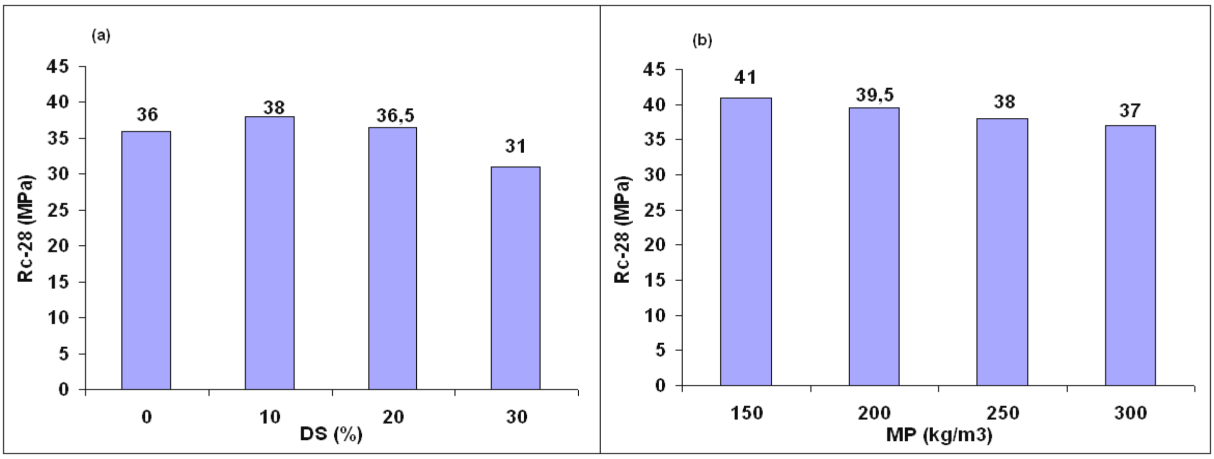

Fig 9. Compressive strength at 28 day for FSC: (a) Effect of DS, (b) effect of MP.

4. Conclusions

The following conclusions can be drawn from the present study:

- The increase of MP content in FSC improves the flowability (by increasing slump flow and decreasing v-funnel flow time).
- An optimal DS content is obtained (10 %), for which the flowability of FSC is improved (a highest slump flow and a lowest v-funnel times).
- The relationship between the mini-slump and slump flow of FSC was evaluated by a linear regression. In result, correlation coefficient is 0.91, indicating a close relationship between the two tests. The relationship between the mini-slump and slump flow studied for flowing sand concretes indicates that mini-slump values between 250 and 330 mm are sufficient to predict a slump flow ranged between 550 and 850 mm of FSC (interval recommended by AFGC).
- Successful self-compactibility of FSC is obtained, but is not in the limits suggested by AFGC and EFNARC recommendations, notably with v-funnel time results.

Even thought, there are much work on self-compactibility of flowing concretes, test methods stipulation are not universally accepted rules. Degree of toleration depends on the engineering judgement, material type and variety. Further research is necessary to establish proper adequacy between flowability and stability of FSC.

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