Influence of natural pozzolana content on self-compacting concrete durability properties

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Abstract. This paper presents the results of an experimental investigation on the rheological properties, compressive strength and durability of Self-Compacting Concrete (SCC) containing local Pozzolana. Pozzolana with a fineness of 3500 cm²/g has been used at different percentages (0%, 10%, 15%, 20% and 25%) as partial cement replacement. Cement content, water to binder ratio of 0.4, gravel to sand ratio of 1.0 and superplasticizer content of 1.8% (by weight of cement) were kept constant in all SCC mixtures. Workability, compressive strength, capillary water and water permeability are reported in this investigation. The substitution content of 10% natural pozzolan seems to give the most favorable effect on the rheological characteristics of SCC. However, the strength and the durability results of the SCC containing 10% of natural pozzolan showed a slight decrease compared to SCC control.

1. Introduction
Self-compacting concretes (SCC) are extremely fluid concretes that can be placed into formwork under their own weight without any external vibration [1, 2]. In addition, these concretes must also have homogeneous properties and no segregation. SCC has been successfully used in many construction projects, mainly in structural members with complex formwork and heavily congested reinforcement [3, 4]. It is generally accepted that the use of supplementary cementitious materials (SCM) for the production of vibrated or self-compacting concrete results in many beneficial properties such as low permeability, high sulfate resistance, and low alkali-silica reactivity [5]. Supplementary cementitious materials such as natural pozzolan (NP) and limestone fines are very abundant and their use could significantly decrease the materials cost for concrete manufacturing, eliminate the waste disposal cost and reduce environmental pollutions and dilapidation of natural resources. However, their use in concrete was limited by some factors such as an increase in water demand and a decrease in the rate of strength development in the long term. The effect of NP on fresh and hardened vibrated or self-compacting concrete has been a major research topic for many years [6,8]. It was reported that using NP as cement substitution in SCC affects considerably its rheological properties, as well as long-term mechanical and durability properties [7, 9 to 12]. Using limestone fines as cement replacement enhance the packing density of powder, flowability and prevents segregation of fresh SCC mixtures [13, 12]. However, limited studies have been done so far on the effect of the combination of limestone fines and local natural pozzolan as cement replacement on the fresh and hardened properties of self-compacting concrete.
This paper reports the results of an experimental study on the influence of local natural pozzolan as limestone cement replacement on the rheological properties, compressive strength and durability of self-compacting concrete. Durability properties include water permeability and capillary water absorption.
2. Experimental investigation

2.1. Materials

A commercial limestone cement type CEMII/A-L 42.5 according to EN197-1 was used. A local natural pozzolan from quarry situated in the west of Algeria was used in the present study. The chemical properties of the cement and pozzolan are shown in Table 1. The mineralogical composition of the natural pozzolan determined by the X-ray diffraction is illustrated in Figure 1. The fine aggregates used were crushed sand with maximum size of 0.158 in. [4 mm] and a density of 2.54 g/cm$^3$. The coarse aggregates (CA) were natural crushed limestone, with maximum size of 8 mm and 16 mm, with a density of 2.57 g/cm$^3$. A polycarboxylate based superplasticizer (SP) was used, which had a solid content and specific density of 30% and 1.05, respectively.

Table 1. Chemical analysis of cement and local natural pozzolan (%)

|          | SiO$_2$ | Al$_2$O$_3$ | Fe$_2$O$_3$ | CaO  | MgO  | SO$_3$ | Na$_2$O | HCl | Li | TiO$_2$ | MnO |
|----------|---------|-------------|-------------|------|------|--------|---------|-----|----|---------|-----|
| Cement   | 21.06   | 3.60        | 4.47        | 63.4 | 1.85 | 2.0    | 0.13    | 0.57| 2.53| -       | -   |
| Pozzolan | 45.67   | 15.10       | 10.14       | 8.98 | 3.45 | 0.19   | 3.00    | -   | -   | -       | -   |

Figure 1. X-ray diffraction of natural pozzolan

2.2. Mix proportions

In order to investigate the effect of the natural pozzolan content on the rheological properties of self-compacting concrete, a total of six SCC mixtures including the control mixture, were prepared with 0, 10, 15, 20, and 25% of natural pozzolan as cement replacement. After a preliminary investigation, all concrete mixtures were cast with constant water to binder (w/b) ratio and total powder content of 0.40 and 495 kg/m$^3$, respectively. An SP ratio of 1.8% by mass of binder materials was used. The proportions of the SCC produced mixes are given in Table 2.
2.3. Test procedures

In the present investigation, the filling ability and deformability of SCC was determined with respect to slump flow, $T_{50}$ spread time and V-funnel flow time. The passing ability of SCC was assessed by L-box test. The segregation resistance was also quantified by sieve test. All tests were performed as per European guidelines for self-Compacting Concrete Committee. Further details on the testing procedure are given elsewhere [13]. For compressive strength test, concrete cubes of 100 mm in size were cast for M35 grade of concrete according to NF P 18-406, 1981. Water penetration depth under pressure for concretes mixtures was determined in accordance to DIN 1048 [14]. In this investigation, 3 bars water pressure was applied at the bottom of a cube specimen of 150 mm for 24h. At the end of the test, the specimen was removed from the permeability cell and then split into two halves in order to measure the penetration depth. The results are the average of two samples at curing age of 90 days.

Water absorption by capillary was measured on prismatic concrete specimens 70x70x280 mm in size, oven-dried at 80 °C until the mass became constant [15]. Specimens were left to cool in an air-tight container. In order to ensure that water flows in a single direction, specimens were sealed on the side.

### 3. Experimental results and discussion

#### 3.1. Fresh SCC properties

3.1.1. Workability: The results of fresh properties of all SCC mixtures are summarized in Table 3. It can be seen from this table that slump flow values varied from 607 to 737 mm for SCC mixtures, with and without natural pozzolana. A reduction of slump flow for all SCC mixtures is associated with an increase of natural pozzolana content. Increasing pozzolana content from 0% to 25% decreases the slump flow by 2%, 4.5%, 12.8%, and 17.6% for SCCNP10, SCCNP15, SCCNP20, and SCCNP25, respectively. The higher slump reduction, the higher NP content is noticed. This reduction in fluidity of SCC mixtures containing pozzolana could be explained by the high water demand associated to the finer particles of the natural pozzolana to achieve a given workability. Turanli et al. [5] reported that high water demand is due to the microporous nature and the angular shape of the particles of the natural pozzolana. The lower slump flow was observed in concrete mixtures containing higher pozzolana content compared to SCC control. Comparing the results of slump flow with SCC criteria [13], it can be observed that all SCC mixtures achieved adequate filling ability and exhibit no segregation. It may be observed from Figure 2 that the substitution of 10% NP gives the lowest value of $T_{500}$ (3.40 s) with an acceptable slump flow of 722 mm and no sign of segregation or bleeding. These results are in agreement with those obtained by several authors [11, 18], who reported a

| Mix composition(kg/m³) | SCCNP0 (Control) | SCCNP10 | SCCNP15 | SCCNP20 | SCCNP25 |
|------------------------|------------------|---------|---------|---------|---------|
| Cement                 | 491              | 443     | 419     | 395     | 371     |
| Natural pozzolan       | 0                | 46      | 70      | 93      | 117     |
| CA 3/8                 | 248              | 248     | 248     | 248     | 248     |
| CA 8/15                | 495              | 495     | 495     | 495     | 495     |
| Sand 0/4               | 924              | 924     | 924     | 924     | 924     |
| Water                  | 196              | 196     | 196     | 196     | 196     |
| w/b                    | 0.40             | 0.40    | 0.40    | 0.40    | 0.40    |
| SP                     | 8.84             | 8.84    | 8.84    | 8.84    | 8.84    |
decrease of slump flow in the case of self-compacting concrete containing NP. All SCC mixtures have satisfactory stability, this may be due to the combination of limestone and natural pozzolana as cement replacement.

Table 3. Fresh properties of self-compacting concrete mixtures.

| Mixtures Designation | Slump flow, in. (mm) | T50 (s) | V-funnel time (s) | L-box | Stability (%) |
|----------------------|----------------------|---------|-------------------|-------|---------------|
| SCCNP0 (Control)     | 737                  | 4.6     | 11.8              | 0.77  | 1.05          | 3.64          | 7.72          |
| SCCNP10              | 722                  | 3.4     | 10.6              | 0.84  | 0.66          | 3.12          | 7.23          |
| SCCNP15              | 704                  | 4.2     | 12.3              | 0.76  | 0.88          | 3.97          | 6.42          |
| SCCNP20              | 643                  | 5.1     | 13.8              | 0.71  | 1.24          | 4.63          | 5.84          |
| SCCNP25              | 607                  | 6.8     | 15.4              | 0.63  | 2.15          | 5.74          | 5.06          |

Figure 2. Slump flow of SCC mixtures

Figure 3 presents the T50 flow time and the V-funnel results for all tested SCC mixtures. As can be seen from this figure, T50 decreases with increasing NP content up to 15% compared to control mixture. A reduction of about 26% and 9% is noticed for SCCNP10 and SCCNP15 mixtures, respectively, compared to control mixture. The same trend is noticed for the V-funnel times. As shown from Table 3, the V-funnel flow time of all SCC mixtures satisfy the requirements of the EFNARC guidelines [4], except SCC mixtures with 20 and 25% NP content. SCCNP10 had the lowest value of T50s and V-funnel flow time compared to control mixture. When the percentage of NP was increased from 10% to 25%, the T50s increases from 3.4 s to 6.8 s and the V-funnel time from 10.7 s to 15.4 s. The higher values of the V-funnel and T50 show clearly the effect of the addition of NP on the viscosity of concrete. A good correlation (R² = 0.91) is observed between the T50 flow time and the V-funnel flow time, as illustrated in Figure 4.
The L-box test results expressed by the ratio \( h_2/h_1 \) of all SCC mixtures investigated in the present study are shown in Figure 5. As shown in this figure, the measured values of passing ability (\( h_2/h_1 \)) varied from 0.84 to 0.63. All SCC mixtures including SCC control present unsatisfactory blocking ratio at the exception of SCC mixture containing 10% of NP (SCCNP10), showing good passing ability and has remained in the target range as specified by EFNARC standards [14]. SCC mixtures with higher NP content present higher viscosity which prevents the passing ability. According to fresh properties results of SCC mixtures containing natural pozzolan as limestone cement replacement shown in Table 3, it is clearly seen that limestone cement concrete mixtures containing local natural pozzolan up to 10 or 15% by weight, satisfy the fresh state behaviour requirements related to high segregation resistance, deformability and passing and filling abilities.
3.2. Hardened SCC properties

Only control SCC and SCC mixtures with 10% of NP content were investigated for strength, water permeability and sorptivity properties.

3.2.1. Compressive strength: Compressive strength results of the control SCC with 10% NP, at the age of 7, 28, 56 and 90 days of water curing are shown in Figure 6. There is improvement in strength performance at all ages of all the mixtures. At the age of 90 days, compressive strengths of control mixture (SCCNP0) and mixture concrete with 10% NP (SCCNP10) were 72.8 N/mm² and 62.8 N/mm², respectively. Strength values of the above SCC mixtures could be considered as acceptable at all ages. A reduction in strength of about 19, 24, 20, and 14% is noticed for mixtures with 10, 15, 20 and 25% NP compared to control concrete mixture. This reduction could be attributed to the decrease of workability of SCC mixtures with the increase of the natural pozzolana content. These results are in agreement with those obtained by many researchers [11, 7], who reported a reduction in compressive strength in the long term of SCC mixture with NP in comparison with concrete control mixture.

Figure 6. Compressive strength of SCC mixtures

3.2.2. Water penetration depth: Figure 7 shows the water penetration depth for SCC mixtures with and without natural pozzolan at the age of 90 days. The higher penetration depth was observed in SCC mixtures containing 10% NP fines (SCCNP10). There is an increase of 21.3% of the water penetration depth for SCCNP10 compared to SCCNP0.
depth for SCCNP10 mixture compared to SCC control. This may be related to the connectivity of the pore structure of the self-compacting concrete containing natural pozzolan.

![Figure 7](image)

**Figure 7.** Water depth penetration for SCC mixtures with 0 and 10% NP

### 3.2.3 Capillary water absorption

Figure 8 shows the capillary water absorption as a function of square root of time for SCC mixtures containing natural pozzolan as limestone cement replacement at the age of 90 days of curing. As can be seen from this figure, the sorptivity values were 0.0018 in./min^{1/2} [0.046 mm/min^{1/2}] and 0.00236 in./min^{1/2} [0.060 mm/min^{1/2}] for SCCNP0 and SCCNP10, respectively. The results show clearly a systematic increase of the sorptivity as the content of natural pozzolan increased. This increase is about 23% compared to SSC mixture control. This finding is consistent with the water penetration depth results. This indicates there is higher capillary water absorption when NP is incorporated in the mixtures. This may be attributed to the presence of higher interconnected pores compared to SCC mixture without natural pozzolan.

![Figure 8](image)

**Figure 8.** Capillary water absorption of self-compacting for SCCNP0 and SCCNP10 at 90 days of curing.
4. Conclusions
Based on the results of this experimental investigation on the influence of natural pozzolana as limestone cement replacement on SCC mixtures, the following conclusions can be drawn:

1. The flowability of SCC mixtures decreases with increasing level of cement replacement substitution by natural pozzolan.
2. The use of a combination of limestone and NP as cement replacement provides good stability for SCC mixtures.
3. Partial cement substitution with 10 to 15 % of NP was found to be the optimum value with an adequate filling ability, passing abilities and good stability.
4. Partial replacement of cement by NP in SCC decreases the compressive strength, increases water penetration depth and increases the capillary water absorption.

5. References
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